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THE CHESTER SERIES IN ILLINOIS[1]

STUART WELLER
University of Chicago

PART I

The Mississippian rocks in Illinois occupy three distinct areas along the western and southern borders of the state. The northernmost of these areas is the larger, and extends from southern Mercer County on the north to northern Madison County on the south. Throughout this entire distance, except for an interval in Pike, Calhoun, and Jersey counties, where older rocks are exposed, the rock formations of the Mississippian system constitute the Mississippi River bluffs. This area also includes the Mississippian strata which are exposed in the valley of the Illinois River as far north as Scott, Brown, and Schuyler counties. Nowhere in this area do the higher formations of the system occur, the youngest formation exposed being the Ste. Genevieve limestone, in the summit of the bluffs above Alton.

The second of the three areas occupies portions of St. Clair, Monroe, Randolph, and Jackson counties. This area includes about 85 miles of the Mississippi River bluffs from a short distance below East St. Louis to the gap formed by the valley of the Big Muddy River, and at only one locality in this entire distance, at

[1] Published by permission of the Directors of the Geological Surveys of Illinois and Missouri.

Valmeyer in Monroe County, are any formations other than the Mississippian exposed. The greatest width of this area is in Monroe County, where the Mississippian formations form the surface rocks for a distance of about fifteen miles back from the river bluffs, where they pass beneath the Pennsylvanian strata. Within this area both the lower and upper series of Mississippian formations are present, and it includes the typical area of the Chester series, as these rocks were described by Hall and Worthen more than half a century ago.

The third area of Mississippian rocks in Illinois is in the extreme southern portion of the state, where these formations constitute the surface rocks throughout a belt ranging from fifteen to thirty or more miles in width, across Union, Johnson, Pope, and Hardin counties. The greater portion of this area is occupied by the upper Mississippian formations of Chester age, although the lower formations do occupy considerable areas in Union and Hardin counties. The northwestern corner of this southern belt is separated from the central area by the valley of the Big Muddy River in Jackson County.

The main portion of this paper will be devoted to a discussion of the Upper Mississippian or Chester series, although the Lower Mississippian, or Iowa series as it may be called for want of any comprehensive name already in use, will be given some consideration in the discussion of the geological history.

The Iowa series was subdivided into a number of well-recognized formations more than half a century ago, mainly through the work of James Hall[1] in Iowa, although some attempt at subdivision had been made before Hall's time, and the subdivisions and classification has been somewhat elaborated in later years. In the main, however, the divisions established by Hall constitute the formations that are recognized at this time. Not so with the upper Mississippian. The early workers generally recognized in this series a more or less confused succession of limestones, shales, and sandstones, and but little attempt was made to subdivide the series. Hall gave the name Kaskaskia limestone to the whole of the succession above a conspicuous sandstone formation in the Mississippi

[1] *Report on the Geological Survey of Iowa* (1858).

River bluffs of Randolph County which was commonly called the "Ferruginous Sandstone." Worthen used the name Chester limestone for the same beds which Hall called Kaskaskia, but included this Chester limestone with the underlying sandstone in what he called the "Chester Group."

While both Hall and Worthen based their descriptions of the upper Mississippian rocks upon observations made for the most part in the second of the areas which have been mentioned, Henry Engelmann carried on field studies in the more southern counties of the state, under the direction of the Illinois Geological Survey. In Johnson, and in the counties to the east and west, Engelmann recognized an alternating succession of limestone and sandstone members of the Chester Group, ten in all, which he designated by the numbers 1 to 10, beginning the numbering at the top. The sandstones in the series received the even numbers and the limestone and shale members the odd numbers. The only one of these members to which a distinct name was given was No. 8, which was called the Cypress sandstone[1] from the good exposures in the bluffs of Cypress Creek, but even this name was abandoned in the later reports by Engelmann and was never used by Worthen.

The real importance of the Chester series in the Mississippian as a whole is well shown by its comparative thickness. The whole of the lower Mississippian or Iowa series has a thickness of approximately 1,000 feet, which was subdivided at an early time, as has been stated, into a succession of well-defined formations, but the Chester series, with a maximum thickness of more than 1,200 feet, commonly has been treated as a single formation by all geologists up to a very recent date.

The first serious attempt to subdivide the Chester was made by Ulrich[2] in 1905. He recognized four formations as follows: 4. Birdsville formation; 3. Tribune limestone; 2. Cypress sandstone; 1. Ste. Genevieve limestone.

The observations which led to this division of the Chester into definite formations were inadequate for the proper understanding of the whole series, and mistakes of so serious a character were

[1] *Trans. St. Louis Acad. Sci.*, Vol. II, Part 1 (1863), p. 189.

[2] Prof. Paper, *U.S. Geol. Survey*, No. 36.

made that it has not been possible to adapt any part of the scheme to the more recent work on the series. In the first place the Ste. Genevieve limestone was mistakenly included in the Chester Group because of the failure to recognize that the upper member of this limestone as defined, the Ohara, was really made up of two very distinct parts, only the upper one of which is really Chester, and this "Upper Ohara" really has no place whatsoever in the Ste. Genevieve limestone when that formation is properly limited in accordance with its typical exposures in Ste. Genevieve County, Missouri. In the second place the sandstone designated as Cypress by Ulrich was not the Cypress of Engelmann, but the bed that was properly sandstone No. 10 of that author. In the third place, beds which really belong in three totally different positions in the Chester series were designated as Tribune limestone. The limestone at Tribune, Kentucky, which gave origin to the name, has more recently been shown to occupy a position far above that designated for the formation, and is in fact representative of a limestone member far up in the Birdsville formation as defined by Ulrich. At another locality the so-called Tribune is a limestone beneath the sandstone that was mistakenly called Cypress, while elsewhere it does occupy the position assigned to it in the definition of the formation, above the miscalled Cypress sandstone. In the fourth place the Birdsville formation of Ulrich comprises a succession of limestones, sandstones, and shales, and is as lacking in utility as a formation as was the older name, Chester formation.

The work upon which the present paper has been based has been carried on continuously under the auspices of the Illinois State Geological Survey, from 1911 to the present time, and was preceded by more general observations upon the Chester series since 1906. From 1911 to the present time the work of mapping in detail the Chester series in Illinois has been in progress, and it has now covered the counties of St. Clair, Monroe, Randolph, Jackson, Johnson, Pope, and Hardin. The only portion of the Chester belt across the state that has not been studied and mapped in detail at the present time is in Union County and a corner of Jackson, and reconnaissance observations in Union County have

shown that very little if anything new in the section can be looked for there.

In the course of these studies it has been found to be necessary and perfectly practicable to subdivide the Chester series into sixteen distinct formational units, which can be distinguished and mapped with ease. The limestones of the series, with one possible exception, are all continuous across the state, from their first appearance from beneath the Pennsylvanian strata in St. Clair, Monroe, or Randolph counties, on the northwest, to Hardin County at the extreme southeastern part of the belt. The sandstone formations, however, are not all continuous across the state; one has its greatest development in the west, thins out, and disappears to the east. Several of them have their great development in the east and become much thinner or disappear entirely in the more western portion of the state. The two uppermost sandstones of the series, however, are present uniformly across the state.

This entire series of Chester formations in Illinois may be arranged in three larger groups that possess rather distinct faunal characteristics, and these three divisions may be designated as lower, middle, and upper Chester. The names of these Chester formations, with their arrangement in the larger divisions are as follows:

Upper Chester Group:

16. Kinkaid limestone
15. Degonia sandstone
14. Clore limestone
13. Palestine sandstone
12. Menard limestone
11. Waltersburg sandstone
10. Vienna limestone
9. Tar Springs sandstone

Middle Chester, or Okaw Group:

8. Glen Dean limestone
7. Hardinsburg sandstone
6. Golconda limestone
5. Cypress sandstone

Lower Chester Group:

4. Paint Creek limestone
3. Yankeetown formation, and Bethel sandstone
2. Renault limestone
1. Aux Vases sandstone

In the naming of these units, those formations are designated as limestones which include notable limestone beds. In all cases such formations include a considerable amount of shale, in some

cases, locally at least, more shale than limestone, and some of them do include minor arenaceous layers. They are called limestones, however, because they are primarily calcareous as distinguished from the alternating sandstone formations. Each of these formations will be considered briefly, their leading lithologic and faunal characteristics will be pointed out, as well as their geographic distribution in the state, and in some cases their distribution beyond the limits of Illinois, in part at least. This will be followed by some statements concerning the geological history of the Illinois basin in Chester time, and its relations to the history of the preceding Iowa time.

LOWER CHESTER GROUP

Aux Vases sandstone.—The Aux Vases sandstone is typically exposed in the Mississippi River bluffs of Randolph County, Illinois, and Ste. Genevieve County, Missouri. It is the formation that was called "Ferruginous sandstone" by the early Mississippi valley geologists, the name Aux Vases being first used by Keyes in 1892,[1] from the exposures in Ste. Genevieve County, Missouri, near the mouth of River Aux Vases. It was the belief of Engelmann and also of Worthen that this basal sandstone in the Mississippi River section was the exact equivalent of sandstone No. 8, or Cypress sandstone of Engelmann's Johnson County section. With such a correlation accepted, Keyes name would be synonymous with the earlier Cypress. In the assumption that the Aux Vases–Cypress correlation was correct, the name Aux Vases was abandoned in our earlier work in Illinois. It was early recognized, however, that there was a stratigraphic break within the arenaceous beds of the basal portion of the Chester series in Monroe and Randolph counties, and with the belief that the name Cypress covered all of these beds and that the Aux Vases was the exact equivalent of the Cypress, the name Brewerville[2] was used by the writer for that portion of the sandstone which lies beneath the break. Later, when studies in the more southern counties of Illinois established the fact that the Cypress and the old "Ferruginous sandstone" were not equivalent, and when studies

[1] *Bull. Geol. Soc. Amer.*, Vol. III, p. 296.

[2] *Trans. Ill. Acad. Sci.*, Vol. VI (1913), p. 121.

across the Mississippi River, in Missouri, showed that the typical section of the Aux Vases was the exact equivalent of the beds for which the name Brewerville had been used, the latter name was abandoned and the name Aux Vases adopted for the lowest sandstone formation of the Chester series in the Mississippi River section.

In its surface outcrop this formation is restricted to a belt through Monroe and Randolph counties, Illinois, continuing into Ste. Genevieve County, Missouri. The formation is a very massive, fine- or medium-textured sandstone in thick beds, in most places more or less conspicuously cross-bedded. Its color on freshly broken surfaces is a soft brown tint, in some localities becoming nearly white. Not infrequently it is mottled with small, dark-brown specks. On long-exposed weathered surfaces, the color in most localities is a darker brown than that of freshly broken surfaces. The massiveness of the formation is well shown in the Mississippi River bluffs between Prairie du Rocher and Modoc and in some of the picturesque gorges which have been eroded in the formation where it is crossed by stream valleys. No fossils of any sort have been found in the Aux Vases sandstone in Monroe or Randolph counties.

The unconformable relations of the Aux Vases sandstone upon the underlying Ste. Genevieve limestone are well shown in a number of places in Illinois. The uneven line separating the two formations can be clearly seen in the Mississippi River bluffs above Modoc. Elsewhere there is an important basal conglomerate in the Aux Vases, such conglomerates being well exposed two miles southeast of New Design, in S.E. $\frac{1}{4}$, S.W. $\frac{1}{4}$, Sec. 28, T. 3 S., R. 9 W., and again five miles southeast of Waterloo in the bluffs of Rock House Creek, in S.W. $\frac{1}{4}$, Sec. 4, T. 3 S., R. 9 W. Still another excellent exposure of the basal conglomerate, apparently resting upon the St. Louis limestone rather than the Ste. Genevieve, is about 6 miles west of Red Bud, in S.E. $\frac{1}{4}$, N.E. $\frac{1}{4}$, Sec. 4, T. 4 S., R. 9 W. A very excellent exposure of this same basal conglomerate is exposed in the Mississippi River bluffs just below McBride, Perry County, Missouri. The pebbles in these conglomerates are practically all chert, they are more or less angular for the most part,

and were clearly derived from the underlying Ste. Genevieve or St. Louis limestones.

The presence of these conglomerate beds establishes the fact that subsequent to the deposition of the Ste. Genevieve limestone, the calcareous sediments hardened into limestones, the cherts which are clearly secondary in origin were formed, and were in essentially the same condition in which they are found today. Then an erosion period set in and in places the entire thickness of the Ste. Genevieve limestone was removed, along with a part of the St. Louis limestone. The subsequent sedimentation laid down the sands of the Aux Vases formation. This interruption in the deposition of the sediments of the Mississippi Valley section must have represented a considerable length of time, and it must be reckoned as an important break in Mississippian history. Other phenomena connected with this sedimentary break will be discussed later, in connection with the geological history.

Beyond Monroe and Randolph counties, to the south, the Aux Vases sandstone has not been certainly identified. There is, however, a flaggy sandstone, about 20 feet thick, in the base of the Chester section east of Anna, in Union County, Illinois, which may be an extension of the Aux Vases, but in view of the fact that this sandstone contains numerous fossils in some beds, while the Aux Vases is quite barren of fossils, and further that sandstone beds are commonly present in the Renault formation of Monroe and Randolph counties, it is possible that this Union county sandstone may be younger than any part of the Aux Vases, and is perhaps referable to the Renault.

The maximum thickness of the Aux Vases sandstone is about 75 or 80 feet, and it varies from this amount to nothing at all, for in places the overlying Renault formation overlaps the Aux Vases and rests upon the underlying Ste. Genevieve limestone. In the more southern counties of Illinois, east from Union County, the position of the Aux Vases sandstone in the section is represented by an unconformity in the midst of the so-called "Ohara limestone member" of the Ste. Genevieve limestone, as described by Ulrich.

Renault limestone.—It would perhaps be better to call this unit the Renault formation, for in addition to its limestone content it

includes much shale and sandstone. It is, however, the first epoch of calcareous sedimentation in Chester time, and while locally there were considerable accumulations of clastic materials near the shore lines of the period, at a distance from the shore the material deposited was wholly limestone and calcareous shale. The name of the formation has been derived from Renault township, the southernmost township in Monroe County. The belt of outcrop of the formation crosses the whole of Monroe County in a north and south direction, and extends northward across the southwestern portion of St. Clair County and southward across the northwestern corner of Randolph County. The outcrops of this formation along Hickman Creek, in St. Clair County, are the most northerly exposures of any Chester formation. In a southerly direction the formation is exposed west of the Mississippi River across the southeastern corner of Ste. Genevieve County, Missouri, and continues for a short distance into Perry County.

Throughout the area of outcrop of the Renault in these Mississippi River counties, the formation is constituted of a very great variety of sediments, limestone, sandstone, and shale being represented, with each type of rock exhibiting great variation in its lithologic characters. In fact, one of the characteristics of the formation in this typical region, is its notable heterogeneity. This great variety in sedimentation is doubtless due to the beds having been laid down in proximity to the shore line of that time.

Beyond the Mississippi River counties, the Renault is known in Union County and from here it outcrops in a continuous belt, except where it is interrupted by faulting, across Illinois to Hardin County, and is also known across the Ohio River in Kentucky. In Union County the formation contains a considerable amount of clastic material in its lower part, perhaps including the flaggy sandstone east of Anna, which has already been mentioned as possibly representing the Aux Vases. Besides this sandstone and some overlying, variegated shales there is nearly or quite 100 feet of limestone referable to the Renault in the Union County section, and the limestone continues across the state, but not everywhere with this thickness. In the southeastern part of the state, especially in Hardin County, and also in Crittenden County, Kentucky,

there are some shaly beds at the base of or just beneath the Renault which have been called the Shetlerville formation, from Shetlerville, Hardin County, Illinois. These beds might perhaps be considered as a member of the Renault rather than as a distinct formation, but they are characterized by certain faunal elements that are somewhat different from the overlying Renault. There is some reason to believe that the Shetlerville beds are represented in the lower portion of what has been called Renault in Union County, but further detailed field work is necessary to establish such a conclusion. East of Union County all of the beds of the Renault or Renault-Shetlerville interval are limestones and more or less calcareous shales.

In the region of its typical development in Monroe County, Illinois, the Renault exhibits a maximum thickness of about 100 feet, but it varies from this maximum to a minimum of less than 20 feet, and doubtless actually thins out to nothing at all. The exposures of the formation in Ste. Genevieve County, Missouri, vary in thickness from about 46 feet to 75 feet or more, and there may be a maximum thickness of 100 feet in the county. In Union County there is 100 feet or more of Renault, but to the east of this county the formation in combination with the Shetlerville, is somewhat less than this, varying from 60 to 80 feet in most sections.

The Renault formation rests unconformably upon whatever lies beneath it, wherever it has been observed in Illinois and Missouri. In the Mississippi Valley counties it overlaps the Aux Vases sandstone and in many places rests upon the older Ste. Genevieve or even on the St. Louis limestone in places. The sub-Renault unconformity is well indicated by the presence of a basal conglomerate at a number of widely separated localities. The best exhibitions of this conglomerate are in St. Clair County, Illinois, on a tributary of Hickman Creek three miles northwest of Millstadt, and in Ste. Genevieve County, Missouri, about halfway between the mouth of Saline Creek and St. Marys. In both of these localities the underlying formation is the Aux Vases sandstone. The conglomerate is constituted of rounded pebbles of chert with an occasional pebble of igneous rock, ranging in size from two inches in diameter to a fraction of an inch. All through the southern counties of Illinois

the Renault-Shetlerville rests unconformably upon the Ste. Genevieve limestone, and this unconformity must represent a time interval not only equivalent to that between the Renault and Aux Vases in Monroe and Randolph counties, but a very much greater time during which the Aux Vases sandstone was deposited and also the time interval preceding the Aux Vases during which the underlying Ste. Genevieve and St. Louis limestones were solidified and their secondary chert formed, following which the whole of the Ste. Genevieve and a part of the St. Louis limestones were removed by erosion in some parts of the region. The unconformity represented by all of these events in Mississippian history must be considered as being of great importance in the classification of the Mississippian as a whole.

The limestones of the Renault are all more or less fossiliferous wherever they occur, and in some localities faunas of considerable magnitude can be secured. One of the forms which can be found with careful search, wherever good exposures of the Renault are present, is the crinoid *Talarocrimus*. This crinoid genus is represented by several species whose geographic distribution is somewhat different, but the same species is known to occur in localities as far apart as Monroe and Hardin counties. A peculiar feature of the genus is its two basal plates, and nearly all of the Renault species have the suture between the two plates somewhat impressed, giving to the base a distinctly bilobed form. These bases and the separated radial plates are the portions most commonly met with, and from these fragments the species cannot be certainly determined, but these bases alone seem to be sufficiently characteristic to be distinctive of the Lower Chester faunas, and they are much more commonly met with in the Renault than in the Paint Creek, the higher limestone unit of the Lower Chester. Another fossil form which is very characteristic of the Lower Chester beds, is the bryozoan *Cystodictya labiosa*, which occurs in both the Renault and the Paint Creek, but has nowhere been observed in any higher formation. The Renault fauna can be differentiated from that of the higher Paint Creek limestone, among other ways, by reason of the much less number of *Archimedes* and *Pentremites*, representatives of both of these genera being very conspicuous in the Paint

Creek while *Archimedes* especially, which is such an abundant form in most of the Chester faunas, is inconspicuous in the Renault in most localities, and in very many collections does not occur at all.

The basis for correlating the Renault across the entire state of Illinois, from St. Clair County to Hardin County, is not only the position of the formation in the stratigraphic column, but also the uniformity of the fossil faunas which occur in the formation. Every species which has been recognized in the Shetlerville-Renault faunas of the southern counties, with the exception of four which are wholly restricted, so far as known, to the Shetlerville beds of Pope and Hardin counties, are known to be present in the typical Renault of Monroe County, except one form which is known in the Paint Creek. Furthermore, the especial index fossils of the Ste. Genevieve limestone have nowhere been found in association with the Renault-Shetlerville fauna. While it is not possible in this place to enter into a discussion of the details of the faunal characters of the horizon, it can be said that most detailed studies of these Lower Chester faunas seem to establish without any doubt the paleontological correlation of the Renault horizon across the entire state.

The sandstone beds of the Renault are commonly less massive than those of the Aux Vases, and they not infrequently contain the fossil trunks of a species of *Lepidodendron*, while no fossils at all have been observed in the Aux Vases.

Yankeetown chert[1] *and Bethel sandstone.*[2]—Succeeding the Renault formation in the Monroe-Randolph County area in Illinois, there is a thin, but very peculiar and persistent bed, which has been called the Yankeetown chert. This formation is siliceous throughout, much of it is a true chert, but in many localities it is seen to include numerous sand grains and locally it is a quartzite. The bedding of the formation is exceedingly irregular and knotty in many places, but locally at least it is quite even. In many places the rock exhibits a distinct, horizontally banded appearance, the separate bands being slightly different in color and only a small fraction of an inch in width. As ordinarily seen in surface outcrops

[1] Weller, *Trans. Ill. Acad. Sci.*, Vol. VI (1914), p. 124; also *Ill. State Geol. Surv.*, Monog. I (1914), p. 25.

[2] Butts, *Mississippian Formations of Western Kentucky* (1917), p. 63 .

the Yankeetown is rather light colored, and it may be detected in many places by the presence of the fragments of nearly white chert scattered through the surficial deposits.

The thickness of the Yankeetown in the Mississippi River counties nowhere exceeds 20 feet, and in places it is perhaps less than 10 feet thick. In spite of its thinness, however, the Yankeetown is very persistent, and is uniform in its characters from a point in St. Clair County not more than eight or nine miles south of East St. Louis, to near Lithium in the northern part of Perry County, Missouri.

Where the Lower Chester formations reappear in Union County, Illinois, the horizon of the Yankeetown is occupied by a sandstone formation quite different in character from the Yankeetown, which has been named the Bethel sandstone by Butts from outcrops in Kentucky. This sandstone holds its position in the Chester section from Union County to Hardin County, except where the outcropping belt is interrupted by faulting, although in southern Johnson County there is a short interval where the formation is entirely lacking. In the first section in Union County, east of Anna, where the Bethel sandstone has been observed, its thickness is comparable to that of the Yankeetown in Monroe and Randolph counties. It is certainly not greater than 20 feet, and perhaps does not exceed 10 feet. Traced to the eastward across the southern counties to the eastern edge of Johnson County, the Bethel nowhere exhibits a thickness greater than 25 or 30 feet, and at one locality at least, in Johnson County, it is lacking altogether. In western Pope County the formation is interrupted by a great, down-dropped fault block, and where it is exposed to the east of this fault block it is considerably thicker, and continues to increase to the east, attaining a thickness of at least 100 feet in southwestern Hardin County.

This sandstone continues southward across the Ohio River into Kentucky, and it is this formation which Ulrich mistakenly considered to be the equivalent of the Cypress sandstone of Engelmann, an error which he has acknowledged and corrected in his latest contribution to the subject.[1]

[1] *Formations of Chester Series in Western Kentucky* (1917), p. 8.

Wherever the contact of the Bethel sandstone with the underlying Renault is exposed, there is evidence of unconformity between the two formations. In the Ohio River bluffs in southeastern Hardin County this contact is well exposed, the lower layer of the sandstone, 6 to 18 inches in thickness, is composed of fragmental material consisting of flat pebbles, slabs more or less irregularly disposed, much lime sand, quartz sand of large, rounded grains, with many fragments of fossils, some of which are worn and rounded. The actual line of contact between the two formations is uneven and undulating. At Indian Point, in southern Johnson County, the basal layer of the Bethel sandstone is a lime conglomerate with more or less flattened pebbles up to two or three inches in maximum dimension. The unconformity of the Yankeetown upon the underlying Renault in the Mississippi River counties, is suggested by the varying thickness of the Renault, and by the uniform character of the Yankeetown, resting in different places upon limestone, shale, and sandstone layers of the Renault.

The correlation of the Yankeetown-Bethel horizon entirely across the state must be based upon the correlation of the underlying and overlying formations, both of which are abundantly fossiliferous. No determinable fossils have anywhere been collected from the Yankeetown, and the invertebrates that have been found in the Bethel are a few very imperfect examples of common Chester types of brachiopods and bryozoans. This sandstone does contain, in places, numerous fragmentary plant remains, mostly tree trunks, of which the only form that can be identified is *Lepidodendron*, probably of the same type that was present in the sandstone layers of the Renault, and which is present in most of the Chester sandstones.

Paint Creek limestone.[1]—Overlying the Yankeetown and Bethel formations is the Paint Creek limestone and shale. In the Mississippi River counties, extending from St. Clair County, Illinois, to Perry County, Missouri, there is present in the lower part of this formation, a persistent bed of deep-red, non-laminated clay or shale, 12 to 15 feet in thickness. Between this red clay and the

[1] Weller, *Trans. Ill. Acad. Sci.*, Vol. VI (1914), p. 125; also *Ill. State Geol. Surv.*, Monog. I (1914), p. 26.

Yankeetown for a thickness of about 10 feet there is a series of bluish, calcareous shales with platy limestone layers, and above the red bed there are other calcareous shales which pass up into limestones, thinly bedded and shaly below, becoming more massive above, these beds being succeeded by more shale beds some of which are variegated red and blue in color. Although there are other reddish or at least variegated shale beds elsewhere in the Chester section, there is no bed anywhere in the series in Illinois that can be mistaken for the deep-red clay bed of the lower part of the Paint Creek formation. Not only is this bed recognizable in surface outcrops, but it can be easily detected in many well records.

The red shale bed of the Paint Creek formation outcrops at intervals throughout the Chester belt from St. Clair to Randolph counties, the northernmost exposure being about one mile northwest of Millstadt. The formation continues across the Mississippi River into Missouri, and the southernmost exposure is in northern Perry County of that state. Between these two localities the same red shale bed is exposed at many localities. It is exceedingly uniform in its characteristics, and where it is met with it is absolutely impossible to mistake it for any other bed in the Chester series.

The limestones of the Paint Creek formation are similar in lithologic character to many other limestones of the Chester series. The several beds are separated by shale layers varying in thickness from an inch or so to several feet, and the limestone beds themselves vary in thickness from less than one foot to three or four feet. Most of the shale beds are more or less calcareous, but above the main mass of limestone there is a considerable body of shale in many sections that is little or not at all calcareous, and is variegated red and blue or purple. Most of the limestone beds are crystalline, some are quite pure and white, others are more impure and much darker in color.

In the southern counties of the state, from Union to Hardin, the Paint Creek is represented mostly by shales, with only subordinate limestone layers, commonly very thin and exhibiting considerable variation in the entire amount that is present. The deep-red shale bed is wanting in the section in these southern

counties, but the shales that are present commonly weather into a red, residual clay which somewhat resembles the material in the red bed of the Mississippi River section. When not weathered, the Paint Creek shale of the southern counties is very fissile, breaking into thin, brittle flakes which are slightly olive green in color when dry, but appear quite black where the exposures are in situations where the rocks are kept constantly wet. In one locality in Johnson County a bed of somewhat variegated red and blue shale has been observed similar in character to some of the beds in Monroe County.

The limestone layers included in the Paint Creek formation in the southern counties vary greatly in character. In places some of these layers are very siliceous, some of them being little more than layers of sand firmly cemented with calcium carbonate, other layers are hard, dense, and compact with few or no sand grains, still other beds are quite free from silica, and some of them, at least, are more or less coarsely crystalline, dark limestone, quite like some of the beds in the more typical exposures of the formation in Monroe County.

The fauna of the Paint Creek is uniform in its essential features, through the full extent of the formation in Illinois. It has much in common with the faunas of the Renault, and the two formations together constitute the two fossiliferous horizons of the Lower Chester. The bryozoan *Cystodictya labiosa* is common in both horizons, as are the species of *Talarocrinus* with bilobed bases, but the Paint Creek fauna includes a much greater number, both of individuals and species, of *Pentremites*, and the bryozoan genus *Archimedes* is far more abundant than in the Renault. The same species of *Pentremites* are present in the fauna from St. Clair to Hardin counties.

The Paint Creek occupies the position in the section which was originally assigned to the Tribune limestone by Ulrich, though it is by no means the equivalent of the formation so named, at Tribune, Kentucky. More recently Butts[1] has proposed to substitute the name Gasper for Tribune, because of the unfortunate choice of

[1] Butts, *Mississippian Formations of Western Kentucky* (1917), p. 64.

that name for the formation by Ulrich. The Paint Creek is the equivalent of the higher portion, at least, of the Gasper limestone of Kentucky.

MIDDLE CHESTER GROUP

In passing from the Lower to the Middle Chester formations, the region of typical and more complete development is found to be in the more southern counties of Illinois, rather than in the Mississippi River counties. As in the case of the Lower Chester, the Middle Chester is constituted of four formations, two siliceous and two calcareous.

Cypress sandstone.—This is the formation for which Engelmann chose the name Cypress sandstone, from the exposures in the bluffs of Cypress Creek, Union County, but it is not the sandstone for which Ulrich used the same name in the report on "The Lead Zinc and Fluorspar Deposits of Western Kentucky."[1] The formation is continuously present in the Chester section from Hardin County at the east to Union County at the western extremity of the southern belt of outcrop of the formations. It is a very massive, cliff-forming sandstone, and except where it is interrupted by faulting in Hardin, Pope, and Johnson counties, it forms the upper portion of a nearly continuous escarpment across the state which is a conspicuous topographical feature. The formation is more uniform in its character throughout its extent in these counties than any other sandstone formation in the Chester series. Some other sandstones are just as massive and make just as conspicuous cliffs in places, but they do not retain such a character throughout for the reason that the massive portions of the other sandstones are much more interrupted, both vertically and horizontally, by thinly bedded and less resistent layers.

The lithologic character of the Cypress is similar to other sandstones of the series, or at least to certain portions of most of the other sandstones. It is rather fine in texture, yellowish brown in color, with more or less cross-bedding, although certain portions of the formation are conspicuously even-bedded, and in places, especially in the upper portion of the formation, the even beds

[1] Prof. Paper, *U.S. Geol. Surv.*, No. 36 (1905).

suggest the regular courses in a well-built masonry wall. The weathered surfaces of the cliffs become darker colored than the freshly broken rock, and in places more or less iron stained. The fossils of the Cypress sandstone consist of more or less fragmentary plant remains, the only recognizable form being *Lepidodendron* trunks.

It has not been possible to measure the exact thickness of the Cypress sandstone in any section in the southern counties of the state. The base of the formation, resting upon the Paint Creek shale, can be approximately determined in many places, but the top of the section in these same sections is in all cases missing and the upper portion has been more or less reduced by weathering. The greatest actual thickness that has been observed in a cliff is about 70 feet, but the thickness has been estimated as 110 feet in at least one section, and the average thickness across these counties is about 100 feet.

In tracing the stratigraphic position of the Cypress sandstone into the section of the Chester series of the Mississippi River counties, the sandstone is found to be much reduced in thickness and much less massive in character. In this section, as originally described by the writer,[1] a sand and shale formation overlying the Paint Creek limestone was named the Ruma formation. The later study of the section in the more southern counties has shown that the sandstone of the Ruma should be considered as the thinned-out margin of the Cypress sandstone, and that the shales below should more properly be considered as being a part of the Paint Creek. With this interpretation the name Ruma becomes superfluous, and Cypress may be extended to include these sandstone beds of the Ruma in Monroe and Randolph counties. In following the section still farther, into Missouri, it is found that the Cypress sandstone disappears entirely, and the super-Cypress limestones rest directly upon the Paint Creek.

In a recent contribution Ulrich[2] has proposed the correlation of the Cypress sandstone of the southern counties with the Lower

[1] Weller, *Trans. Ill. Acad. Sci.*, Vol. VI (1914), p. 126; also *Ill. State Geol. Surv.*, Monog. I (1914), p. 26.

[2] "The Formations of the Chester Series in Western Kentucky, and Their Correlates Elsewhere," *Ky. Geol. Surv.*, Plate D, opposite p. 47.

Okaw limestone of Monroe and Randolph counties. Such a correlation, however, is not supported by the evidence of the fossils and the faunal studies of the Chester have established beyond question the exact equivalence of the Golconda limestone of the southern counties with the Lower Okaw in Randolph County.

Golconda limestone.—When the Chester section in the Mississippi River counties was first elaborated by the writer, the name Okaw limestone was given to a thick series of limestones with shale partings overlying the so-called "Ruma" formation. It was recognized that this was probably a composite formation, and an attempt was made to map the higher beds as a separate unit from the lower ones, but this was finally abandoned because the heavy covering of drift seemed to make such a procedure impracticable. When the studies were carried into the more southern counties, it developed that the limestone beds equivalent to the Okaw were divided into two distinct units separated by an important sandstone formation. The lower of these two units has been named Golconda limestone from the excellent exposures in the Ohio River bluffs just above Golconda, in Pope County.

The Golconda limestone is constituted of a succession of limestone and shale beds, the details of which are commonly obscured by surficial material, and it is not known whether the details of the succession of beds are uniform throughout the areal extent of the formation. The limestone beds vary considerably in character, but in general they are of a light- or dark-gray color, and more or less crystalline in texture, with some layers oölitic. The shales are fully as variable and perhaps more variable than the limestones. Some of them are highly calcareous, while others are quite purely argillaceous; many of the beds are gray or buff, but others are dark and even black, and at a number of localities a layer of reddish shale has been observed. In the basal part of the formation there are shale beds with a considerable content of sand, and even some thin sandstone layers, but beds of this character are not present higher up in the formation.

In tracing the Golconda limestone into the Mississippi River counties, where it is represented by the lower and main portion of

the Okaw limestone, the characteristics of the formation remain much the same, although the local details are different. As in the southern counties there is a succession of limestone and shale members, but there is a larger content of limestone in the more western region. The limestone beds themselves are crystalline in texture, like those in the south, they vary in color from essentially white to dark gray, the lighter colors on the whole being more dominant in Monroe and Randolph counties, and the oölitic beds being much more conspicuous. The shale beds are similar in the two regions.

The establishment of the continuity and equivalence of the Golconda and the lower portion of the Okaw is based not alone upon their occupying an equivalent position in the section, but upon the paleontological characters as well. One of the notable horizon markers of this lowest limestone formation of the Middle Chester is the little brachiopod *Camarophoria explanata*. This species is unknown in the Lower Chester faunas, but is a common member of all the Middle Chester faunas, and is present, abundantly in places, in some of the Upper Chester formations. The horizon where it is first introduced in the section can be considered as being well toward the base of the Golconda limestone. In the southeastern counties of the state one of the most reliable guide fossils for the lower Golconda is the Crinoid *Pterotocrinus capitalis*, which is commonly represented by the "wing-plates" alone. This species has not been recognized in Randolph or the adjoining counties, but in this region the near basal beds of the lower Okaw are characterized by the presence of a peculiar and very unusual fauna, for the Chester series at least, composed very largely of small pelecypods and gastropods, including many Bellerophontids. Many of the species of this fauna are undescribed, and some of them are peculiar and extraordinary. In southern Johnson County, at one locality, a fauna has been collected from near the base of the Golconda, in which most of these peculiar basal Okaw species are present, and associated with them are many examples of the characteristic *Pterotocrinus capitalis*. This mingling of forms, so peculiar in character, is assumed to be sufficient evidence to establish the equivalent of the Golconda with the lower Okaw, and the

name Golconda may be extended to include the equivalent beds in Randolph and Monroe counties.

The lithologic character of the Golconda limestone is of such a nature that its contacts with the underlying and overlying formations are not commonly exhibited, and at no locality have both of the contacts been observed in the same section. This condition makes the determination of the thickness of the formation a matter of estimate. In the neighborhood of Golconda the interval between the top of the Cypress sandstone and the base of the Hardinsburg is about 150 feet, and as this is the interval occupied by the Golconda, an approximate thickness of 150 feet may be assumed for the formation. The thickness of the whole of the Okaw limestone in the Mississippi River counties is something over 200 feet, and of this total thickness the lower Okaw, which is the equivalent of the Golconda, includes approximately 150 feet, being about equal to the Golconda in its typical exposures.

Hardinsburg sandstone.—Overlying the Golconda limestone and resting upon it unconformably is an important sandstone formation which in many places is scarcely less massive than the Cypress. Butts has given the name Hardinsburg[1] to this formation from a Kentucky locality. In general appearance, texture, color, etc., the Hardinsburg closely resembles the Cypress, and in isolated outcrops not seen in relation to an underlying or overlying limestone, it would not be possible in many places to differentiate the two formations. The Hardinsburg, however, is somewhat less massive on the whole, and includes considerable amounts of more thinly bedded sandstones in places. In general the Hardinsburg is somewhat thinner than the Cypress, although it does have a maximum thickness of at least 100 feet. There are places, however, in the southern counties where the thickness does not exceed 30 feet, and the average thickness is probably about 60 or 70 feet.

In the Mississippi River counties there is no conspicuous sandstone formation which corresponds in position with the Hardinsburg in the southern counties. There is present, however, within the formation to which the name Okaw was originally given, a horizon marked by a discontinuous sandstone layer which in

[1] *Miss. Form. W. Ky.* (1917), p. 96.

places is as much as 10 feet thick, elsewhere being wanting altogether. This layer is best exhibited in the vicinity of Chester, in the outside prison quarry at Menard, between Menard and Chester, and just below Cole's mill in Chester. This sandy layer in the Okaw is undoubtedly the attenuated margin of the Hardinsburg sandstone which has its greatest thickness in the southeastern part of the state, for the limestone beds above it possess many faunal characters which unite them with the limestone formation overlying the Hardinsburg in the southern counties.

Glen Dean limestone.—The Glen Dean limestone is another formation that has been named by Butts from exposures in Kentucky.[1] In the southern counties of Illinois the formation resembles the Golconda in general character, being composed of interbedded limestone and shale layers, but in most localities the proportional amount of shale is much greater in the Glen Dean, in places nearly the whole of the formation being shale. Many of the limestone beds in the formation are similar lithologically to those of the Golconda, being gray in color and crystalline in texture for the most part, but locally certain of the layers are somewhat more dense and compact.

The Glen Dean has certain faunal characters that differentiate it rather sharply from the Golconda. One of the best index fossils is a species of bryozoan, *Prismopora serrulata*. Examples of this species are triangular in cross-section, with three faces bearing zoöecia, these prismatic zoaria dividing at intervals. This bryozoan is not entirely confined to the Glen Dean, for it has been observed rarely in the Golconda, and is not uncommon in the Vienna limestone, still higher than the Glen Dean, but it is far more common in the Glen Dean than elsewhere, and in places some of the limestone ledges of this formation are veritable *Prismopora* gardens. *Pentremites' spicatus* is another characteristic form, which has not been observed outside of this formation, but it is far less common than the *Prismopora*. A number of other bryozoans and some other fossil forms are more or less conspicuous in this formation, which are nearly everywhere or entirely unknown from other Chester horizons.

[1] *Miss. Form. W. Ky.* (1917), p. 97.

In the Mississippi River counties the whole assemblage of fossil forms which characterize the Glen Dean formation in the southern counties has been found to be present in those beds of the Okaw limestone which overlie the interrupted sandstone horizon in the midst of that formation, and these upper Okaw beds may be correlated directly with the Glen Dean and this name may be extended to include these beds in the Randolph-Monroe County section.

The thickness of the Glen Dean in the southern counties exhibits some variation from a minimum of 40 feet to a maximum of perhaps 75 feet. In the thinner sections it is apparently the higher beds that are missing, due perhaps, to the erosion of the upper surface of the formation before the deposition of the overlying sandstone. The thickness of the equivalent beds in Randolph County is similar to that in the southern counties, the usual thickness commonly being about 60 feet.

[*To be continued*]

A CORRELATION OF THE PRE-CAMBRIAN FORMATIONS OF NORTHERN ONTARIO AND QUEBEC[1]

H. C. COOKE
Geological Survey of Canada, Ottawa

In a paper recently published in the *Journal of Geology*[2] the writer correlated the pre-Cambrian formations of northern Quebec as well as facts obtained during the last ten years would permit. The formations most satisfactorily correlated were a number of scattered patches of sediments which had been given the local names Pontiac, Mattagami, Broadback, and Brock series. In composition, succession, structure, and external relations these scattered patches of sediments were deemed sufficiently alike to warrant substituting the general name Mattagami series for the local names. The position of the Mattagami series in the geologic column is shown in the following succession:

Mistassini limestone
Unconformity
Diabase dikes
Intrusive contact
Cobalt series
Great unconformity
Granite
Intrusive contact
Lamprophyre dikes
Intrusive contact
Mattagami series
Unconformity
Gabbro and anorthosite
Intrusive contact
Granite-gneiss (around Lake St. John)
Intrusive contact
Nemenjish series (Grenville series?)
Abitibi volcanics (basalts, andesites, rhyolites)

During 1918 the writer had an opportunity to examine for the first time the Timiskaming series in the Kirkland Lake district of northern Ontario, and was so impressed by its similarity to the Mattagami series that further opportunity was taken in 1919 to investigate its relation to that series. The results indicate beyond any

[1] Published by permission of the Geological Survey of Canada.

[2] *Journal of Geology*, Vol. XXVII, Nos. 2, 3, 4, 5, 1919.

reasonable doubt that the Mattagami series and the Timiskaming series of Kirkland Lake may be correlated and grouped together under a single name.

LOCATION

The area of Mattagami series nearest to the Kirkland Lake district is the Pontiac area lying south of the National Transcontinental Railway between the Ontario-Quebec boundary and the

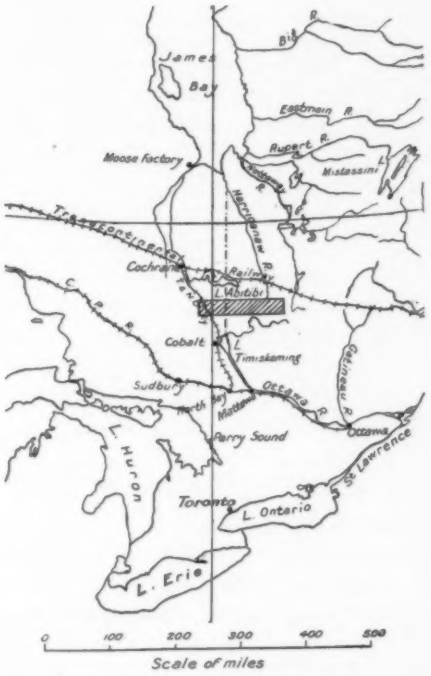

FIG. 1.—Index map showing location (hatched) of area dealt with in this paper

Bell River. Between the two districts lies the Larder Lake district, 12 miles in width. The three districts together form a narrow strip of territory about 130 miles from east to west, and 25 miles from north to south (Fig. 1). The shaded area in Figure 1 shows

the general location of this strip within which lie the sediments whose correlation is dealt with in this paper. The Timiskaming Northern Ontario Railway passes through its western end, affording access to the important mining center of Kirkland Lake through Swastika station, and to Larder Lake through Dane station. The only access to the Quebec portion of the area is by canoe from Lake Timiskaming, Larder Lake, or the National Transcontinental Railway.

PREVIOUS WORK AND CONCLUSIONS

Reconnaissances along easily accessible water routes were made as early as 1900 by W. J. Wilson,[1] W. G. Miller,[2] L. L. Bolton,[3] Walter McOuat,[4] W. A. Parks,[5] J. Obalski,[6] and J. F. E. Johnston,[7] but the first detailed work appears to have been that of Brock[8] and Bowen,[9] in 1908, at Larder Lake. In the four years following the whole of the area shown in Figure 1 was mapped in more or less detail by A. G. Burrows, and P. E. Hopkins,[10] E. L. Bruce,[11] M. E. Wilson,[12] R. Harvie,[13] and J. A. Bancroft.[14]

These writers have reached very different conclusions regarding the age and external relations of the sediments in this strip of territory. Burrows and Hopkins (1912) consider the sediments of Teck, Lebel, and Gauthier townships to be a single series of inter-

[1] W. J. Wilson, *Geol. Surv. Can., Sum. Rept.*, 1901, pp. 117A–130A; *Geol. Surv. Can., Mem. No. 4*, 1910.

[2] W. G. Miller, *Ont. Bur. of Mines, Rept. No. 14*, pp. 261–68, 1905; *Rept. No. 11*, pp. 214–30, 1902.

[3] L. L. Bolton, *Ont. Bur. of Mines, Rept. No. 12*, pp. 173–90, 1903.

[4] W. McOuat, "Rept. of Prog.," *Geol. Surv. Can.*, 1872, 1873, pp. 112–35.

[5] W. A. Parks, *Geol. Surv. Can., Sum. Rept.*, 1904, pp. 198–225.

[6] J. Obalski, *Mining Operations in the Province of Quebec*, 1906, pp. 5–27; 1907, pp. 42–56.

[7] J. F. E. Johnston, *Geol. Surv. Can., Sum. Rept.*, 1901, pp. 130A–143A.

[8] R. W. Brock, *Ont. Bur. of Mines Rept. for 1907.*

[9] N. L. Bowen, *Ont. Bur. of Mines Rept. for 1908.*

[10] Burrows and Hopkins, *Ont. Bur. of Mines Rept. for 1913.*

[11] E. L. Bruce, *Ont. Bur. of Mines, Rept. for 1912.*

[12] M. E. Wilson, *Geol. Surv. Can., Mem. Nos. 17, 39.*

[13] R. Harvie, *Report of Mining Operations in the Province of Quebec during 1910.*

[14] J. A. Bancroft, *Report of Mining Operations in the Province of Quebec during 1912.*

bedded conglomerates and greywackes folded into a tight syncline with vertical or very steep limbs. Miller correlates this series with a similar closely folded conglomerate near Cobalt, previously called Timiskaming series. They recognize that it is much older than the Cobalt series, since the latter is found in Grenfell Township, to the west of Teck, lying flat within a quarter of a mile of the folded Timiskaming. The Cobalt series is regarded as probably Upper Huronian or Animikean in age, and the Timiskaming as Lower Huronian.[1]

The sediments continue without interruption (Fig. 3) from Gauthier Township eastward into McVittie and McGarry townships (Larder Lake district), where they are described by Brock and Bowen (1907) and later by M. E. Wilson (1908–9) as consisting of slates, carbonate rocks, and greywackes interbedded with basic altered lavas and therefore as of Keewatin age. Some steeply dipping conglomerates found to the north and south of the slates and other rocks are mapped as isolated patches of Cobalt conglomerate deformed by local disturbance.

Some four miles to the east of Larder Lake there outcrops the sedimentary series named the Pontiac schists by M. E. Wilson. These are separated from the Larder Lake sediments by a band of flat-lying sediments belonging to the Cobalt series (Fig. 3). The Pontiac series has been described by M. E. Wilson and J. A. Bancroft as a series of interbedded conglomerate and greywacke, folded into a vertical position, overlying the Keewatin unconformably, and underlying the Cobalt series with great unconformity. The similarity of the descriptions of the Pontiac conglomerates and greywackes and the corresponding members of the Timiskaming series of Kirkland Lake is pronounced.

The geological descriptions which have been briefly summarized appeared to the writer to indicate either that some error had been made in the study of one of the areas, or that there was more there than any of the geologists had recognized. Under the latter hypothesis it was conceived that there might be two ancient sedimentary series in the district, one of which was the better developed in each area, and that a different one had been

[1] *Ont. Bur. Mines, Rept. No. 22*, pp. 123–27, 1913.

recognized by each set of investigators. To determine if possible which of these hypotheses was the correct one, the writer in 1919 visited Larder Lake and made a study of the part of the area in doubt.

INVESTIGATIONS AT LARDER LAKE (FIG. 2)

A conglomerate outcropping prominently on the Larder townsite was the first thing to attract the writer's attention. This conglomerate is mapped by Brock and Wilson as belonging to the

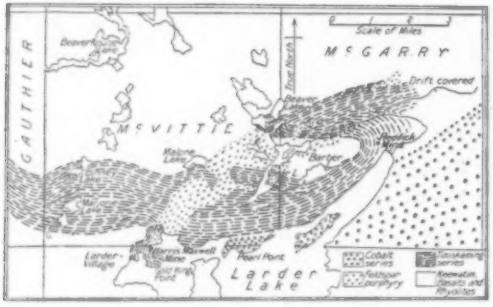

FIG. 2.—Larder Lake area

Cobalt series, but evidently with reservation on the latter's part, as he describes it thus:[1]

> There is an area of mashed conglomerate on the north shore of Larder Lake, at Larder City, which has been intruded in a most complex manner by a hornblende lamprophyre, vogesite. *The pebbles of this conglomerate differ from the normal type* in that they consist entirely of quartz porphyry, rhyolite, and iron formation. . . . . The occurrence of the lamprophyre cutting the sheared conglomerate suggests that this conglomerate may be the equivalent of Dr. Miller's Timiskaming series.

Again, on page 37:

> In the neighbourhood of Larder Lake there are numerous areas of conglomerate which have been greatly mashed in a direction parallel to the strike of the underlying Keewatin. These conglomerates might have any one of the three following relationships to the other rocks of the region: (1) They might be Keewatin conglomerates deposited between the volcanic flows of

[1] *Geol. Surv. Can., Mem. No. 17*, p. 38.

that series in a manner somewhat similar to the interflow conglomerates which occur in the lower portion of the Keewanawan series. (2) They might belong to an older Huronian series, that is, a series younger than the Keewatin but older than the *undisturbed* Huronian. (3) They might be portions of the ordinary flat-lying series which have suffered local disturbance.

Wilson concluded to map all the mashed conglomerates under the third hypothesis, as locally sheared Cobalt series. The only evidence in support is given on page 38:

> It was also observed that in some outcrops where the mashed conglomerate has a considerable vertical thickness, the schistosity appears to diminish from the base upward, as if the contact of the flat-lying Huronian and the Keewatin might have served as a plane of deformation. This phenomenon can be seen in a conglomerate hill situated on the northern boundary of claim H.J.B. 21, in McGarry Township.

A plane of contact very commonly does function as a gliding plane during folding, so that the rocks close to it are apt to be more schistose than those farther away without regard to the age of the series; but the foregoing inference would be valid only if the schistose strata passed gradually into flat-lying beds, which they do not. The writer found that this conglomerate forms part of the conglomerate of the Timiskaming series.

To the east of Larder Village, across a small bay, Gold King Point projects into the lake. The greater part of this point is mapped as Keewatin on the early maps, with a small patch of conglomerate near the southeastern extremity; but the point was stripped clean of vegetation by fire three years ago, and the present exposures show clearly that the conglomerate is not a patch but a continuous band about 30 feet in width, dipping vertically and with its strike swinging from north 60 degrees west at the southeastern tip of the point to north near the Harris-Maxwell mine (Fig. 2). The conglomerate, like that on the Larder townsite, contains pebbles of basalt, rhyolite, jasper and iron formation. It is intruded by a feldspar porphyry like that of Kirkland Lake, and by dikes of lamprophyre. On the east side, where not intruded by porphyry or lamprophyre, it is in contact with massive basalt, exhibiting good pillow structure, and contains basalt pebbles. The rocks on the west of the conglomerate are not Keewatin, but well-bedded greywackes, showing fine lines of cross-bedding in

places; the dip and strike of the greywacke parallel those of the conglomerate.

It is evident therefore that these rocks, with those on the Larder townsite, are parts of a small tightly folded syncline, the axis of which has a north-south strike between the village and the Harris-Maxwell mine. It was also apparent that they lie unconformably on the greenstones, as the rhyolite, basalt, jasper, and iron formation are all members of the underlying volcanic complex.

A mile and a half to the east, on Pearl Point (Fig. 2) normal conglomerate and slate of the Cobalt series outcrops. The conglomerate is massive, at least 100 feet thick, and crowded with pebbles of all sizes. From 75 to 90 per cent of the pebbles are granite, the remainder other rocks. The conglomerate dips 15 degrees to 20 degrees, and is overlain by the normal argillite of the series, fine grained, black, and well bedded, containing an occasional pebble. The composition, succession, and structure of these rocks is so utterly different from those at Larder Village only $1\frac{1}{2}$ miles away that it is difficult to conceive them to be of the same formation.

Accordingly the writer returned to trace northward the band of conglomerate that passes across the Larder townsite. It runs somewhat east of north for about half a mile, then swings to the east across a drift-filled valley, on the other side of which it was easily picked up again and traced a short distance farther north, till, turning west, it passes beneath a large sand plain. Two miles to the west it has been mapped by both Wilson and Burrows on the shore of the Blanche River.

About half a mile to the north of the Harris-Maxwell mine (Fig. 2) an interesting set of relations occurs. The basal band of conglomerate, composed as before mainly of pebbles of rhyolite, jasper, and iron formation, here striking south 40 degrees east and with vertical dips, is overlain conformably on the east by interbanded greywacke and conglomerate, the conglomerates gradually becoming finer grained, passing into coarse grits and then into fine grits. Above the grits and greywackes occur some hundreds of feet of soft, slaty argillites, whose strike and dip parallel those of

the conglomerate. All these rocks are greatly broken up by intrusive dikes and masses of porphyry.

Lying on the upturned edges of these rocks is a second conglomerate, a massive rock composed almost entirely of greenstone fragments with about 10 per cent of granite pebbles, lying flat, and showing vague cross-bedding in places. This conglomerate occurs in irregular patches and knobs, evidently erosion remnants, lying indifferently on the older slates, greywackes, grits, and conglomerates. The writer concluded from the composition, which is characteristic of the base of the Cobalt conglomerate, and from the lack of deformation that it is an erosion remnant of the Cobalt conglomerate found to the east in larger masses; the areal relations to the underlying sedimentary series show that there is a large unconformity between the two.

The earlier geologic maps show a number of patches of conglomerate, mapped as Cobalt series, lying to the north of the areas of Larder slate, in many cases some distance to the north and within areas of Keewatin. These conglomerates proved on examination to consist invariably of beds dipping to the south at angles varying from 60 to 90, and frequently badly sheared. Their composition is like that of the conglomerate of the Larder townsite, in that the pebbles are largely of rhyolite, banded chert, jasper, and iron formation, with some basalt, although commonly the proportion of rhyolite is larger and that of iron formation smaller than on the townsite. The rocks to the north of the conglomerate band are invariably basalts except around Malone Lake, where rhyolite occurs; and almost invariably they exhibit pillow structures and other characteristics of lavas. The conglomerates were found to form, not isolated patches, but a strong band, continuous throughout the district, except where broken by intrusive masses of porphyry, and where, for a short distance to the east of Barber Lake, it has been obliterated by thinning and intense shearing.

The rocks to the south of the conglomerate band were then carefully examined, as some of them had been previously mapped as Keewatin. A great deal of excuse for the earlier mapping was found, in that in many cases the rocks are massive, dark green, chloritic rocks, indistinguishable in the average hand specimen

from the usual altered basalt. This is particularly the case in the area about 2 miles due north of Larder Village. But careful detailed examination showed that nowhere are there any ellipsoidal structures or amygdaloidal or other textures characteristic of lavas, although the massive character of the rocks indicates that these textures would have been preserved had they ever existed. On the contrary, bedding was observed at many points where exposures were clean and free from moss. Stratification is rarely prominent, but always distinct, being marked by slight changes in color, composition, and grain. It was clear therefore that these rocks are not lavas, but greywackes, presumably composed of the débris of eroded basalt flows. This conclusion was strengthened by finding in many places on clean weathered surfaces occasional angular or subangular grains of basalt.

Since these rocks are thus proved to be sediments, not lavas, the earlier conclusions as to the interbedding of the Larder Lake sediments with lavas become invalid, together with the conclusions drawn therefrom as to the Keewatin age of the sediments. As there is no observed unconformity between the different bands of sediments, it is concluded that they form a single series, infolded with the older volcanics into a tight syncline. This series of sediments rests unconformably on the Keewatin, since the basal conglomerate is composed mainly of Keewatin material, and is overlain with structural unconformity by the Cobalt series. It is intruded by feldspar porphyries and by lamprophyre dikes. Because of its stratigraphic position, lithological similarity, and geographic continuity (Fig. 3) the series is clearly a continuation of the Kirkland Lake Timiskaming.

Figure 3 shows the Timiskaming to be a strong band $1\frac{1}{2}$ to 2 miles in width, with a general east-west trend. Less than 3 miles due east of where the band is concealed by the Cobalt series on the east side of Larder Lake, the Pontiac series outcrops, and continues as a strong band for another hundred miles eastward. J. A. Bancroft has shown that the external relations of the Pontiac series are identical with those of the Timiskaming series; both overlie the Keewatin with unconformity, are intruded by granites, and are overlain by the Cobalt series with great unconformity.

Both are deformed along east-west axes and the basal conglomerates of both are so similar that the writer has been unable to distinguish them. In view of these facts there can be no reasonable doubt as to the correlation of the two series. Since the Pontiac series has already been correlated with other ancient sediments of northern Quebec under the general name of Mattagami series, a general correlation of northern Ontario and

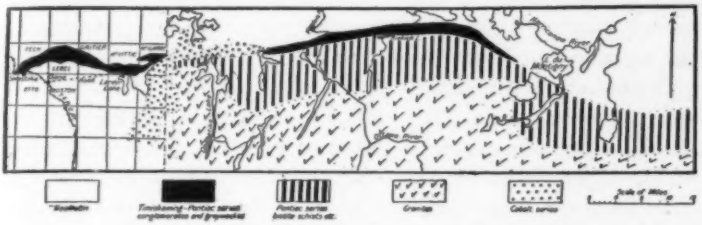

FIG. 3.—Sketch map showing the lineal distribution of the Timiskaming-Pontiac series in Ontario and Quebec.

Quebec is thus established. The name Timiskaming, which has priority, will henceforth be used in this report in referring to these sediments both in Ontario and Quebec, replacing the name Mattagami series.

ECONOMIC VALUE OF THE CORRELATION

The correlation thus established possesses a certain economic value which may now be briefly discussed. The writer has recently shown[1] that in the Matachewan district of northern Ontario valuable gold deposits have been formed through the action of juvenile solutions originating from a body of cooling syenite porphyry. Similar porphyries are found in many places through northern Ontario, and very commonly in association with gold deposits. While the genetic connection of the gold deposits with the porphyry has never been definitely proved, so far as the writer is aware, in any district but that of Matachewan, still the frequency with which the association occurs is extremely suggestive. The porphyries intrude the Keewatin volcanics in dikes, batholiths, and rarely sills; when they intrude the Timiskaming series the bedded

[1] *Economic Geology*, Vol. XIV (1919), pp. 281–301.

structure of the latter causes them commonly to assume the form of sills. Gold deposits have not as yet been found around the batholiths, presumably because the upper contacts, where juvenile waters might have deposited ores, have been eroded away, while the lower surfaces are not exposed. The porphyry dikes frequently have gold deposits associated with them, but it is commonly found that such deposits are small, presumably because the dikes are not large enough to have afforded any great amount of juvenile water. The most favorable form for the porphyry to assume would seem in theory to be the sill, which combines a large volume with a relatively small thickness, together with the exposure of both edges, in tilted rocks. The facts correspond with the theory, inasmuch as within the boundaries of the Timiskaming series, where the porphyries commonly form sills, gold discoveries have been very numerous, and many of the discoveries have been developed into producing mines.

The syenite porphyry is found in large amount throughout the Kirkland and Larder Lake districts, and was found by the writer in Quebec, to the east of the Larder Lake area, and also on Lake de Montigny, near the east end of the Pontiac area. It would seem likely therefore that it may be found intruding the Timiskaming series throughout its whole length of 130 miles although perhaps not in such volume as in the Kirkland and Larder areas. Thus the correlation between the Timiskaming and Pontiac series increases the Timiskaming area, already recognized as very favorable for prospecting, to four times its former known size.

EXTERNAL RELATIONS OF THE TIMISKAMING SERIES

Facts already briefly stated in the foregoing pages indicate that the Timiskaming series overlies the Keewatin unconformably, is intruded by granitic rocks, and is overlain with great unconformity by the Cobalt series. In view, however, of the disagreement that has existed in the past between those studying the districts under consideration, it seems advisable to enlarge somewhat on the previous statements.

Relations to the Keewatin.—The basal conglomerate of the Timiskaming series contains pebbles of all the volcanic series, as

well as a few pebbles of granite and syenite. The volcanics observed in the basal conglomerate include basalt, andesite, rhyolite, iron formation, red jasper, and various cherts and tuffs, many of them possessing well-defined bedding. Schistosity in the pebbles was observed in one place only, near Kenogami station on the Timiskaming and Northern Ontario Railway, where a few pebbles of a peculiar volcanic breccia are sheared. (This statement naturally applies only to such bodies of conglomerate as have not been sheared as a whole. Where this has taken place the pebbles are to be found in all stages of mashing.) The pebbles in the basal parts of the conglomerate are very well rounded, thus evidencing considerable wear before final deposition.

Wilson has argued that the presence of pebbles of the volcanics does not constitute proof of unconformity, and while he does not exclude the possibility of unconformity he regards it as possible that the conglomerates do not represent any long erosion interval. It is true that the presence of the lava pebbles is not full proof of unconformity, and the writer will go farther and admit that even the granite pebbles do not necessarily indicate unconformity, since he has found a few granite pebbles in coarse tuffs interstratified with Keewatin basalts. The conclusive evidence of unconformity is found in the presence of pebbles of iron formation, bedded chert, etc. These are water-laid sediments, as is clearly shown by their thin uniform bedding, their frequent association with thin-bedded tuffaceous clastics, and their association in other places with pillow lavas, which are now commonly recognized as subaqueous extrusions. The presence and association of these pebbles in the Timiskaming conglomerate indicates conclusively that before the conglomerate could have been laid down there must have been uplift, some folding, and erosion of the underlying rocks. Unconformity is thus proved.

Relations to the granites.—The relation of the Timiskaming series to the ordinary granite of northern Ontario that contains a great deal of free quartz is not yet known, as such granite is not found in contact with the Timiskaming series at any known point. But granites of this type intrude the Timiskaming series in northern Quebec. At the contacts the sediments are more or

less metamorphosed and recrystallized by the heat of the intrusive, and converted into hornblende and biotite gneisses, occasionally with development of some garnet. Dikes of granite and pegmatite pierce the sediments, and some blocks of the latter are found included in the granites often at considerable distances from the contacts. The included blocks are in all phases of digestion from sharp-angled fragments through phases in which the edges and corners have been partially or completely dissolved to phases in which the only remaining indication of a foreign mass is a vaguely outlined patch of material more micaceous than the surrounding granite. The contact of the granites and Timiskaming is different in degree, though not in kind, from a granite-Keewatin contact, in that it is a fairly sharp line, instead of being a wide zone of blocks of the older rock separated by dikes and masses of intrusive. This is undoubtedly due to the influence of the bedding of the Timiskaming series in controlling the intrusion.

The principal granitic rocks known to intrude the Timiskaming in Ontario are two: a grayish syenite in Lebel Township, and various bodies of syenite porphyry. The syenite body in Lebel Township is presumably, from its shape, a batholith; the porphyries may form fairly large batholithic masses, as in the case of the large mass north of Larder Lake, but more commonly they form smaller bodies the intrusion of which has been largely controlled by the bedding of the Timiskaming. They tend therefore to be sill-like in shape, although they may be observed to cut the bedding in numerous places. The chemical and mineralogical composition of the syenite batholith and the intrusive sills is so similar that there can be little doubt that they are but different forms of the same intrusive magma. The writer has not observed the contact of the Timiskaming series and the batholith in Lebel Township, but the mapping by the Bureau of Mines indicates that it is of much the same nature as the granite contacts in northern Quebec already described. The evidence of intrusion of the sills is more difficult to obtain, since the sills had practically no recrystallizing influence on the sediments, and rarely have a chilled edge, include blocks of sediment, or send off dikes into the sediments. The best evidence of intrusion is the areal evidence,

obtained by mapping. Thus in McGarry Township porphyry masses are seen (Fig. 2) to cut across the bedding of the Timiskaming near its base, into the underlying Keewatin. The same thing on a smaller scale may be observed to the north of the Harris-Maxwell mine, where masses of porphyry cut across the bedding of the sediments, from the conglomerates into the overlying greywackes and slates.

Relations to the Cobalt series.—The Cobalt series overlies the Timiskaming with very great unconformity. The relations of the two series are seen in two places. In Grenville Township, near Kenogami station, the flat-lying Cobalt series outcrops a quarter of a mile northeast of the Timiskaming, which dips 60 to 70 degrees. The Cobalt series outcrops again near the Timiskaming series at Larder Lake. As mentioned previously, a small outcrop of the Cobalt basal conglomerate north of the Harris-Maxwell mine was observed to lie on a peneplaned surface beveling the Timiskaming series and the porphyries and lamprophyres which intrude it. The Cobalt conglomerate here lies in turn on Timiskaming conglomerate, greywacke, and slate, which are tilted into vertical attitudes, as well as on the intrusives. The unconformity is thus clearly proved. The Cobalt conglomerate on Pearl Point (Fig. 2) contains numerous fragments of the greywackes, slates, and porphyries of the Timiskaming series. The Timiskaming therefore suffered intense folding, intrusion, and peneplanation before the Cobalt was laid down on it.

The thickness of strata eroded during the peneplanation which took place before the Cobalt series was deposited has never been estimated, but some data obtained in Boston Township permit of the calculation of a minimum figure. Careful observations made on the structure of the Keewatin in this district and elsewhere throughout northern Ontario and Quebec, show, wherever studied, that it has been thrown into close isoclinal folds, usually upright or slightly inclined, but occasionally overturned. Such a fold is illustrated in Figure 4. Erosion has cut so deeply into these folds as to remove the crests entirely, so that only the steeply inclined limbs may now be observed. In three or four places the writer has found good outcrops directly across the axis of such a fold,

and was thus able to observe directly that the width of the flattened strata along the axis was slight, perhaps 100 feet or thereabouts. It is clear therefore that the minimum amount of erosion necessary to produce such a condition, represented by CC' in Figure 4, can be determined by measuring the thickness of the strata by the usual methods. All that is necessary for such a determination is a knowledge of the position of the axis of an anticline and the next adjacent syncline, which may be observed directly or calculated from the position of some recognizable horizon.

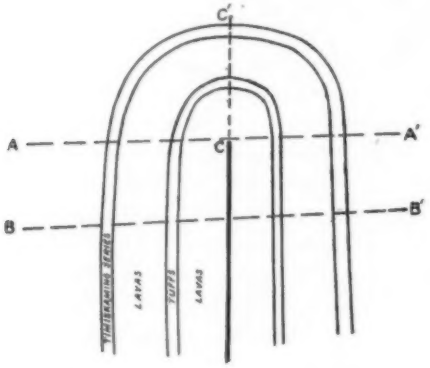

FIG. 4.—Diagram illustrating method of calculating minimum amount of erosion at the base of the Cobalt series.

It need scarcely be emphasized that such a determination of the amount of erosion is no more than a minimum, placing the erosion surface in the position AA' (Fig. 4). It gives no hint of the additional thicknesses of rock removed in the formation of any lower erosion surface BB'.

In Boston and Otto townships a recognizable horizon for purposes of measurement is afforded by a band of well-stratified tuffs approximately 1,300 feet in width which are here interbanded with the basalt flows (Fig. 5) This band was determined, by methods described,[1] to have the north side as the upper. In the

[1] *Jour. Geol*, Vol. XXVII (1919), p. 75.

south part of Boston Township there is a similar band, the upper side of which was determined by similar means to be the south. The bands are of about the same width, the southern one somewhat the wider, as it contains a larger proportion of interstratified basalt flows which could not be separated in mapping. There can be no

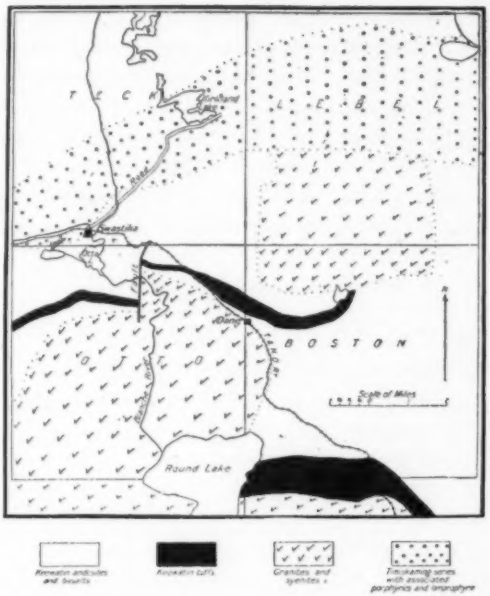

FIG. 5.—Sketch map showing the tuff bands in Boston and Otto townships and their relations to the Timiskaming series.

doubt therefore that the two bands form the limbs of an anticline whose crest has been cut off by erosion. The dips of the strata in both bands average about 70 degrees or higher. At their nearest point of approach the bands are about 17,000 feet apart, so that the axis of the anticline may be considered to be approximately 8,500 feet from the base of each band.

The syenite batholith to the north of the tuffs in Boston Township prevents the calculation there of the thickness of the Keewatin

between the tuffs and the Timiskaming series. About 5 miles to the west, however, in Otto Township, where the tuffs approach the Timiskaming most closely, there is a width of 8,250 feet between the base of the Timiskaming and the base of the band of tuffs. The sum of these two numbers, 8,500 and 8,250, therefore represents the minimum width of the Keewatin between the center of the anticlinal fold and the base of the Timiskaming. Assuming an average dip for the Keewatin of 60 degrees, which is smaller than the average measurement, we arrive at a minimum thickness for the Keewatin of approximately 15,000 feet.

Overlying the Keewatin there was at least 3,600 feet of Timiskaming series so that there were at least 18,600 feet of strata in all removed by erosion before the deposition of the Cobalt series. The actual amount may have been much more than this, however.

AGE

The descriptions of preceding sections show definitely that the Timiskaming series is post-Keewatin and pre-granitic in age, and antedates the Cobalt series by a period sufficient for the peneplanation of a mountainous area, with removal of at least 18,600 feet of rock. Its age may, however, be more closely delimited by the following consideration.

The Cobalt series outcrops in an almost continuous sheet from Larder Lake southwest to the north shore of Lake Huron. Throughout this whole section it lies in gentle open folds, with dips rarely exceeding 20 degrees, and rests on a correspondingly gently warped peneplain that bevels closely folded rocks cut by granitic intrusives. Near Lake Huron, however, this peneplain is directly overlain by the Bruce series, and the Cobalt series overlies the Bruce. There is an erosional unconformity between the Cobalt and Bruce series, representing a time interval sufficient for the removal of 1,700 feet of sediments,[1] but little or no structural unconformity; so that both series, where not disturbed by the Keewanawan folding and intrusion, lie in the same open gentle folds as the Cobalt to the north. It seems evident therefore that

[1] W. H. Collins, *Geol. Surv. Can., Museum Bulletin No. 8*, 1914.

the Timiskaming, which forms part of the ancient, tightly folded, peneplaned basement must be pre-Bruce as well as pre-Cobalt.

W. H. Collins has recently shown that the stratigraphy of the Bruce series in Ontario is closely similar to that of the Lower Huronian of the Marquette region.[1] As the gap between the two districts is filled with Palaeozoic sediments this evidence is probably the best we shall ever obtain for the correlation of the Huronian of northern Ontario with that of the south shore of Lake Superior. Accepting it therefore, it follows that the Timiskaming series is pre-Huronian.

DESCRIPTION OF THE TIMISKAMING SERIES

In Teck Township the Timiskaming forms a syncline whose width averages pretty closely 1½ miles, after subtraction of the widths of intrusive masses of porphyry and lamprophyre. The dip of the limbs varies from 60 degrees to 90 degrees. The maximum thickness, calculating the dip of both limbs at 90, is 4,000 feet; the minimum, calculating both limbs at 60, is 3,400 feet. Commonly the south limb dips 80 to 90 degrees, the north limb about 60 degrees. Calculated on this basis the thickness amounts to about 3,600 feet, a figure which probably approximates the truth. In the western part of McVittie Township, 15 miles east, where the whole width of the syncline is also exposed, the calculated thickness is closely the same.

In Teck Township the whole thickness is made up of interbanded conglomerates and greywackes. At the western end of the syncline near Kenogami station there is a basal band of conglomerate 400 feet thick, overlain by a massive greywacke containing an occasional pebble, the thickness of which is at least 125 feet, and may be much greater. About 3 miles to the east of this near Swastika, the basal conglomerate is over 1,000 feet thick. While there was not time available to make detailed sections of the Timiskaming of Teck Township, these observations, coupled with the alternating conglomerate-greywacke composition throughout the entire thickness, indicate pretty clearly that the sediments here are of subaerial origin, such as beach deposits, or continental

[1] W. H. Collins, memoir in preparation.

deposits from torrential streams; and that the beds, if worked out in detail, will be found to be lenticular in shape.

The basal conglomerate near Kenogami station is composed almost entirely of detritus from the underlying volcanic series. In a railway cut here it is in contact with a serpentinized agglomerate or flow breccia of very unusual composition and appearance. The conglomerate contains numerous rounded pebbles of this material, so that the fact of unconformity is indubitable. These pebbles are also slightly schistose, although the conglomerate and all the other pebbles are quite massive, so far as observed; so that some deformation must have preceded the deposition of the conglomerate.

The conglomerate is crowded with pebbles, particularly near the base where 75 to 80 per cent of the total mass is pebbles. They vary in size up to a foot in diameter, but the majority are from 1 to 4 inches in diameter. They are mostly pretty well rounded and worn. About half of them are longer in one direction than the other, presumably due to their original structure, and the long axes commonly lie parallel to the plane of bedding in the conglomerate. All the pebbles appear to be massive, with the one exception noted above. Approximately 50 per cent are of the light-colored cherty tuff which commonly accompanies rhyolite flows; some of these are probably also rhyolite. Thirty-five to 40 per cent are basalts and gabbros, the latter probably from the coarser-grained parts of basalt flows. The remaining 10 to 15 per cent consist of red jasper, banded chert, porphyry, and the peculiar breccia mentioned above, with here and there one of reddish granite and syenite. In the upper parts of this bed there is a somewhat greater variety among the pebbles. Quite a number are to be found of a quartz porphyry common among Keewatin rocks, and grayish granite pebbles are fairly common.

The matrix of the conglomerate is a rather coarse grit, composed of the small fragments of the rocks which supplied the pebbles.

The conglomerate is massive and unsheared. The stresses developed during the folding have been relieved, not by schisting, but by jointing accompanied by a number of small faults.

Many of the conglomerate beds lying at some distance above the base of the series, as in the second locality mentioned above

about 3 miles to the east of Kenogami, are markedly different from the basal beds, in that the pebbles are mostly small and very sharp angled, so that the rock at first glance gives the impression of a breccia instead of a conglomerate. Cross-bedding is frequently found here, and in general the beds are only a few inches or feet in thickness instead of being thick and massive.

The writer has been unable to make any personal examination of the Timiskaming in Lebel and Gauthier townships, but 12 miles to the east, in the western end of McVittie Township, the stratigraphy of the series is notably different from that described. The series in this third locality is well exposed on the north side of the syncline, on Binney Lake and eastward. On Binney Lake there is approximately 600 feet of interbedded conglomerate and greywacke at the base, striking north 80 degrees east and dipping 60 degrees south. The composition of the conglomerate is approximately the same as at Kenogami, but instead of being in thick massive bands it forms bands a few inches or feet in thickness, interstratified with greywacke. Only one heavy band of conglomerate was observed; it may be about 100 feet thick, and lies near the top of the conglomerate-greywacke complex. The remainder of the section is all massive, thick-bedded greywackes, except at the center of the syncline on Marjorie Lake, where there are some very impure quartzites, now partially altered to sericitic schists. The thickness of the latter was not measured, but is not over 500 feet at most. The total thickness along this section is about the same as in Teck Township, 3,600 feet.

The series maintains the same composition for about 2 miles to the east of the Binney Lake section, except that in this distance the central schistose quartzites become much purer and whiter. About 2 miles to the east of Binney Lake, however, and eastward past Malone Lake as far as Bear Lake the amount of basal conglomerate becomes much larger. The thickness of the basal part is perhaps not any greater than at Binney Lake, averaging about 600 feet; but instead of containing a great deal of greywacke, the whole thickness is of massive conglomerate, while occasional beds of conglomerate were also found in the greywacke for more than a quarter of a mile south of the main conglomerate band. Little can

be said of the remainder of this section, since the rocks above the conglomerate are broken and replaced by a large mass of intrusive porphyry. To the south of the porphyry on Bear Lake, however, a new formation appears, a thin-bedded argillite of about the same composition as the greywacke.

The basal conglomerate was next observed on the west end of Barber Lake, about a mile to the east of Bear Lake. In this distance it has thinned remarkably to only 60 feet. It is overlain by about 100 feet of rather impure sandstone, to the south of which lie the greywacke and argillites of the series. The thickness of the latter was not directly determined and cannot be estimated, since the southern edge of the syncline is covered by Larder Lake. The conglomerate band outcrops along the south shore of Barber Lake, continuing to thin, until about a quarter of a mile east of the east end it was observed to consist of about a foot of rather coarse grit. It was not found again on the south side of the anticlinal nose here (Fig. 2), so that the base of the series for at least half of a mile appears to be a rather impure sandstone. As this is very badly sheared, however, for a width of perhaps 25 feet from the contact, and converted into a featureless sericite schist, it is possible that pebbles may have existed in it but were obliterated.

On the north side of the anticlinal nose, the conglomerate reappears again, gradually thickening to about 30 feet. It consists, like that around Binney Lake, of thin pebbly beds interstratified with beds of greywacke. It maintains this character east of Beaver Lake, where the syncline (Fig. 2) pinches out. On the north side of this syncline, for a distance of about 2 miles east of Beaver Lake, the conglomerate is hidden by drift, and where it reappears it is a rather thin band, perhaps 30 or 40 feet in thickness, over which lies about 700 feet of rather impure quartzite. This is overlain in turn by a second band of conglomerate about 300 feet thick. To the south of this band of conglomerate the rocks are grits and impure quartzites, very poorly exposed. To the east, the lower conglomerate disappears entirely within a mile, replaced by beds of impure quartzite intruded by masses of porphyry. The total width of this mixture is 1,400 feet, of which about three-fourths is porphyry. To the south of this lies nearly 1,000

feet of interbedded argillite and impure sandstone, over which again lies some 250 feet of conglomerate with some interbedded impure quartzite.

The writer's attention has been called by Mr. M. E. Wilson to a peculiarity of some of the sheared conglomerates of the Larder Lake district, which here and there are found to contain squeezed, pebble-like masses distinguished by the presence of chrome-mica or fuchsite. Fuchsite is also characteristic of the altered and sheared porphyry masses of the region, and Wilson is inclined to believe that unconformity is thus indicated between the porphyry and the conglomerates. This, however, is obviously impossible, since, as already shown (p. 317), the porphyries cut the conglomerate and the other members of the sedimentary series. The writer made a careful examination of the composition of the conglomerate wherever it was found unsheared or only slightly sheared, but found no pebbles containing fuchsite. It seems indubitable therefore that the fuchsite in the pebbles of the sheared conglomerate must be formed during the shearing of the conglomerate after its deposition. Fuchsite is not alone characteristic of the sheared carbonated porphyry of the Larder Lake district, but it has been found by the writer in several places in Keewatin rhyolites and rhyolite tuffs which have been subjected to carbonate alteration and subsequent shearing. Pebbles of the Larder Lake porphyry are not found in the Timiskaming conglomerate here, but pebbles of rhyolites in all stages of alteration are common. It is likely therefore that some of these have given rise to the fuchsite pebbles in the mashed types of conglomerate.

The sediments were not traced farther to the east, as the next 2 miles is heavily drift-covered, and beyond this again the Cobalt series overlies. To the east in Quebec the rocks are described by J. A. Bancroft as follows:

> Exposures of a much metamorphosed conglomerate, arkose and greywacke appear at intervals on both sides of the (Kinojevis) river for about three-fourths of a mile. Either vertical or dipping very steeply to the north, and striking nearly east and west, these rocks may be traced to Keekeek lake and the upper portion of the river bearing the same name (about 16 miles). . . . . The conglomerate is chiefly composed of pebbles of Keewatin greenstone, although pebbles of granite and diorite are of frequent occurrence. Originally the

pebbles were well rounded and varied in size up to a foot across; they have been so flattened by pressure that today they possess lenticular forms. . . . . The matrix of the conglomerate as well as the arkose and greywacke have been quite universally converted into biotite schists, partially or completely recrystallized, yet repeatedly exhibiting their originally clastic character. . . . . That the sediments rest unconformably upon the Keewatin is evidenced by the pebbles in the conglomerate and the position which some of the exposures bear to those of the Keewatin.

M. E. Wilson described the sediments thus:

The Pontiac series in the district north of Kekoko and Kinojevis lakes is composed of greywacke, arkose, and conglomerate, which extends in an east-west belt having a width of about 2 miles. . . . . These rocks are all greenish gray or gray in colour, and have all been more or less mashed. The greywacke is everywhere recognized by the quartz grains which it contains. . . . . The arkose is of local extent and differs only from the greywacke in containing more fragments of acidic minerals. The conglomerate consist of mashed pebbles and boulders of granite, rhyolite, and quartz porphyry in greywacke matrix. No pebbles or boulders of basic rocks were seen.

Wilson also indicates on his map that the dips vary from 50 degrees north to vertical.

NEMENJISH SERIES (?)

In the writer's last paper on this subject[1] there were indicated some reasons for believing that a part of the body of sediments mapped as Pontiac series might in reality belong to an older sedimentary series which there were some reasons for believing to be of Grenville age. Briefly stated, these reasons were the absence of basal conglomerate at the east end of the sedimentary band and elsewhere, the occurrence of amphibolites in the Pontiac series, while amphibolites are not elsewhere found in the Mattagami (or Timiskaming) series, but are common in the Grenville and its supposed equivalents; and the occurrence of undoubted Grenville within 30 miles to the south and to the east. The facts described in this paper yield additional evidence on this point. The Timiskaming of Ontario is pretty uniformly about 3,600 feet in thickness through a band over 30 miles in length. As Figure 3 shows, in Quebec, 15 miles to the east, the band widens sharply to more than 10 miles, throughout which the dips average 45

[1] *Jour. Geol.*, Vol. XXVII (1919), p. 201.

degrees north except within 2 miles of the northern edge where they are steeply north or vertical. The dips of the northern edge are due to overturned folding, as the writer has shown.[1] If the series as mapped is all one, its thickness in Quebec is at least 22,000 feet, unless the outcrops have been repeated by folding; but Wilson records no southward dips. On the contrary, the width of the conglomerate-greywacke band, the descriptions of which correspond so closely with those of the Timiskaming of Ontario, is uniformly about 2 miles, or very little greater than that of the Timiskaming to the west. While it is possible therefore that the series does increase in thickness from 2,600 to 22,000 feet by depositional processes within less than 15 miles, the writer considers it more likely, in view of the other evidence, that only the band of conglomerate and greywacke along the north edge of the series as mapped is of Timiskaming age, while much or all of the biotite schists and amphibolite to the south of this band belongs to the older sedimentary series.

ORIGIN OF TIMISKAMING SERIES

The well-stratified nature of the Timiskaming sediments, especially of the upper members of the series, such as the argillites of Larder Lake, indicates that they have been laid down in a body of standing water. The well-rounded pebbles in the basal conglomerate indicate fairly long-continued wear, while the angularity of the fragmental material, in the beds above the proximate base, and its unsorted character indicate either that it has not been carried far before deposition, or else that if carried far the transportation has been very rapid, such as would be afforded by torrential streams from a mountainous area. The undecomposed character of the particles composing the greywackes, etc., indicate rapid removal of detritus after disintegration, such as occurs in any district where there is no vegetation to hold the rock particles in place long enough for decomposition to take place. The great thickness of the basal conglomerate in places and its rapid variations in thickness are characteristic of continental or subaerial deposits as also is the cross-bedding frequently to be

[1] *Ibid.*, p. 200.

observed in the conglomerates and interbedded greywackes. The change in the character of the sediments, from a series of interbedded conglomerate and greywacke on the west to a series on the east in which conglomerate is a relatively minor part, might indicate that the territory to the west which supplied the sediments was higher and more rugged, with more rapid streams, than that which supplied the sediments to the east. This conclusion is strengthened by the fact that the material composing the upper conglomerates in Teck Township is noticeably more angular than that to the east, so much so in fact that many of the conglomerates resemble breccias.

We may infer therefore a large lake or, on account of the thickness of the series, more probably a transgression of the sea due to gradual submergence. To the west of what is now Teck Township there must have been a fairly rugged mountainous or semi-mountainous area, flattening to the east. Vegetation was entirely lacking or almost so. As the sea advanced, a normal thin basal conglomerate was first formed, composed of fairly well-rounded fragments of the underlying rocks. This was supplemented by sharp-angled material brought down by streams, in large amount in the west, in lesser amount in the east. As submergence continued, the deposition of conglomerate ceased altogether in the east to be replaced by that of greywackes and finally argillites, with small amounts of arenaceous materials locally. Submergence apparently was never great enough to cover the mountainous area to the west; or, if so, with it disappeared the last source of sedimentary material in important amount; since the conglomerates and greywackes of Teck are not overlain by finer-grained beds.

NOMENCLATURE

A brief discussion of the nomenclature of the granite of Timiskaming district may be added here, as closely related to the main purpose of this paper. The term Algoman has recently been applied by Miller, Burrows, and others, when referring to granites intrusive into the Timiskaming series but underlying the Cobalt series.[1] The term Algoman was first used in the Rainy Lake district by A. C. Lawson, and was defined by him as applying to

[1] *Ont. Bur. Mines, Rept. No. 22*, Part 2, pp. 123–27, 1913.

granites intrusive into the Middle Huronian but underlying the Upper Huronian or Animikie.[1] The transfer of this term to Timiskaming district 500 miles to the east was made upon a correlation of the Cobalt series with the Animikie, since both series are flat lying and overlie a great unconformity, and a secondary decision that the Timiskaming, as a folded sedimentary series lying beneath the Animikean, was probably Lower Huronian. But with the determination of the Timiskaming series as pre-Huronian in age, while the intrusive granites are found in the Lake Huron area to underlie the Bruce or Lower Huronian, it is clear that the use of the term Algoman is entirely unjustified.

In its place the writer would apply the term Laurentian to these granites. This much-abused term has had an eventful history. It was first applied by Sterry Hunt in 1852 to what had up to then been known as the Metamorphic series, or lower pre-Cambrian. At that time these rocks were supposed to be all sedimentary, on the grounds that their gneissic textures were the remains of original bedding. They had been described in 1847 as consisting of a lower group of reddish and grayish syenitic gneisses, much contorted and generally at high angles, succeeded by an upper series containing important beds of crystalline limestone interstratified with the syenitic gneiss. The two groups were considered to be conformable. Between 1862 and 1865 the Laurentian, still supposed to be all sedimentary, was further subdivided into the Upper Laurentian, Labradorian, or Norian, in which subdivision were placed the great anorthosite bodies in the vicinity of Montreal, and the Lower Laurentian, which was further subdivided into the basal Ottawa Gneiss and the overlying Grenville series of interbedded crystalline limestones, quartzites, and gneisses. One of the first suggestions that part of these rocks might not be sedimentary but intrusive seems to have come from A. R. C. Selwyn, in the *Summary Report of the Geological Survey Canada* for 1877–78, but the first definite conclusion in this regard drawn from field observation is by Vennor, who reported in the director's *Summary Report of the Geological Survey of Canada* for 1879–80 that some of the anorthosites north of the St. Lawrence appeared to be intrusive in the crystalline

[1] *Geol. Surv. Can. Mem. No. 40*, p. 82. 1913.

limestones. Vennor, however, resigned from the Geological Survey in the next year and his report was never published. In 1885, A. C. Lawson published the results of his work in the Rainy Lake region, and demonstrated conclusively that the gneisses there, previously known as Laurentian, were not sedimentary rocks at all, but intrusive; and that, whatever the origin of the gneissic textures, they could not possibly be accounted for as relics of original bedding, since the rock had clearly been fluid enough at one time to permit of the movement through it of fragments of Keewatin. In 1887 he expressed the view that the foliation was due to flowage movements prior to complete solidification. He also considered that the granite gneisses represented the fused floor on which the Keewatin and Couchiching rocks had been laid down, and definitely reparated the term Laurentian to apply only to the intrusive gneisses. In the same year F. D. Adams anounced in the *Summary Report* that his study of the anorthosites north of the St. Lawrence River had shown that the gneissic and massive portions were gradational into each other, so that there was little doubt but that the whole body was of igneous origin. A second statement to the same effect was made by him in the *Summary Report of the Geological Survey* for 1891; but his full report on the subject was not published till 1894. A second report published in 1895 discusses the question of the Lower Laurentian in the district north of Montreal, previously subdivided into the Ottawa gneiss and the Grenville series; and shows that gneissic structures may have originated in many ways other than by original bedding, and that much of the gneiss here, particularly the Ottawa gneiss, is of igneous origin, although gneisses are present also whose composition indicates that they are altered sediments.

From this time it was generally recognized that the granite gneisses are of igneous origin, not sedimentary, and as the sedimentary parts of the old Laurentian series were already known in the literature as the Grenville series, the name Laurentian was restricted to its granitic parts. In many places, particularly in Canada, the name was indiscriminately applied to any pre-Cambrian granite of unknown age; but south of Lake Superior,

where careful detailed geologic work was being done following the discovery of the great copper and iron deposits, it was applied more rigidly only to granites unconformably below the Lower Huronian. In 1905, the International Committee on pre-Cambrian nomenclature defined the term Laurentian as applicable to "the granites and gneissoid granites which antedate or protrude through the Keewatin, and which are pre-Huronian." They added, "In certain cases this term may also be employed, preferably with an explanatory phrase, for associated granite of large extent which cut the Huronian or whose relations to the Huronian cannot be determined."

From 1905 to the present time the term Laurentian has gradually fallen into disuse in Canada. Careful detailed geologic work has been carried on in this period by the Geological Survey, with the use of local names to designate formations, and without any attempt at general correlation until all the necessary evidence has been obtained. In general, no names whatever have been applied to the granite masses, although Miller has called the granite around Cobalt the Lorrain granite. But with the writer's work of last summer, which completed the mapping of a large nuclear area in Ontario and Quebec, and brought in the evidence necessary for correlation and age determination, it appears possible to apply the term Laurentian correctly and rigorously.

The writer suggests that the term Laurentian be defined, in the more rigorous sense intended by the International Committee, to apply only to those granites and granite gneisses which intrude all rocks below the peneplain at the base of the Lower Huronian. Older granites, which will undoubtedly be found some day since the Timiskaming series contains granite pebbles in places and granite pebbles are found in Keewatin tuff beds occasionally, must receive other names when found. Laurentian will therefore apply to all granitoid masses intrusive into the Timiskaming series, and cut off by the peneplain which bevels it. This use of the term for northern Ontario corresponds to the usage in the Marquette district, the nearest pre-Cambrian on the south shore of Lake Superior; where the Laurentian granite is that which underlies the Lower Huronian.

SUMMARY

The present paper is a continuation of that published last summer. Data obtained during the summer of 1919 have shown that the sedimentary rocks at Larder Lake, Ontario, are not interstratified with the Keewatin, as formerly supposed, but are parts of a synclinal sedimentary series overlying the Keewatin unconformably. The series forms a lineal continuation of the Timiskaming series of Kirkland Lake, to the east.

It is shown that the Timiskaming series of Kirkland and Larder Lakes is to be correlated with the Mattagami series of northern Quebec. The name Timiskaming series is applied to both.

The age of the Timiskaming series is discussed, and the conclusion drawn that it is pre-Huronian.

Descriptions as detailed as possible are given of the stratigraphy and thickness of the Timiskaming series, and the mode of origin of the series is discussed.

As the determination of the age of the Timiskaming is also indicative of the age of the granites which intrude them, a brief consideration is given to the question of the proper nomenclature to be applied to these granites. The conclusion is reached that they may properly be termed Laurentian.

THE JUAN DE FUCA LOBE OF THE CORDILLERAN ICE SHEET

J HARLEN BRETZ

There were two large glaciers in western Washington during the latest, or Vashon, glaciation of that region. Each was essentially an elongated lobe of the great piedmont glacier which accumulated between the mountains of Vancouver Island and the British Columbia mainland. One lobe moved southward into the Puget Sound depression, filling it completely and pushing over into the Chehalis Valley to the south. The other moved westward through the Juan de Fuca Valley, extending as a tidewater glacier into the open waters of the Pacific Ocean. Though both of these lobes were augmented to some extent by valley glaciers from mountains in Washington, neither were true piedmont glaciers of these mountains.

Ice from this piedmont glacier in the depression now occupied by Georgia Strait moved almost directly south over the San Juan Islands, striating and grooving rock surfaces from tide-level virtually to the summit of the highest peak of the islands, 2,400 feet A.T.

In Fuca Strait south of the islands, the ice divided into two parts, one continuing southward as the Puget Sound Glacier, the other being deflected to the west and north of west as the Juan de Fuca Glacier. The Puget Sound Glacier pushed as far south as latitude 46° 50′ N., about 80 miles south of the re-entrant angle between the two lobes. Its extra-morainic outwash extended down the Chehalis Valley to the head of Grays Harbor, 30 miles beyond the limits of the ice.[1]

The Juan de Fuca Glacier extended westward along the southern coast of Vancouver Island nearly to Cape Beale[2] and spread

[1] J H. Bretz, "Glaciation of the Puget Sound Region," *Washington Geological Survey, Bulletin 8* (1913).

[2] C. H. Clapp, "Southern Vancouver Island." *Canada Geological Survey, Memoir 13* (1912), p. 144.

out as a broad spatula over the low-lying northwest salient of the Olympic Peninsula south of the strait. It reached westward nearly or quite to longitude 125° W., 10 or 12 miles off the Washington coast beyond Cape Flattery.

There is a narrow foreland between the Olympic Mountains and Juan de Fuca Strait, composed largely of Pleistocene materials. It is separated from the coastal plain west of the mountains by a group of ridges which strike parallel to the shore of the strait. They extend from Crescent Lake to the extremity of the Olympic Peninsula. They are everywhere several hundred feet high and certain summits are mapped as high as 4,000 feet. They serve as a divide between Soleduck River on the south and the short streams tributary to the Strait on the north.

The foreland terrace north of these ridges gradually narrows westward until it disappears, while the valley on the south side, between the ridges and the main mass of the Olympics, broadens and joins the coastal plain facing the Pacific.

The slopes of these ridges bear little or no glacial drift but the valleys between them contain deposits of Vashon till. The till of the foreland and in these valleys is, in general, light in color and contains plentiful granitic material, very much like the Vashon till of Puget Sound. Many erratics are of identical material. It seems clear that the débris was brought from the same feeding grounds north of the international boundary line.

But west of Crescent Lake and south of these ridges, the drift contains a large amount of basalt and dark-colored sandstone and conglomeratic débris which came from the Olympics immediately to the south, and which is not found in the till north of the ridges.

The eastern portion of these ridges apparently served as an imperfect barrier in the Juan de Fuca Glacier between drift from the distant Georgia Strait and from the nearby Olympics. Farther west, however, the ridges were overridden by the northern ice which carried its granitic drift southward almost to the mouth of Quillayute River.

The coastal plain of the Olympic Peninsula is densely forested. There are few roads and clearings. Such as do exist are along the streams. These conditions have forbidden any attempt to trace a

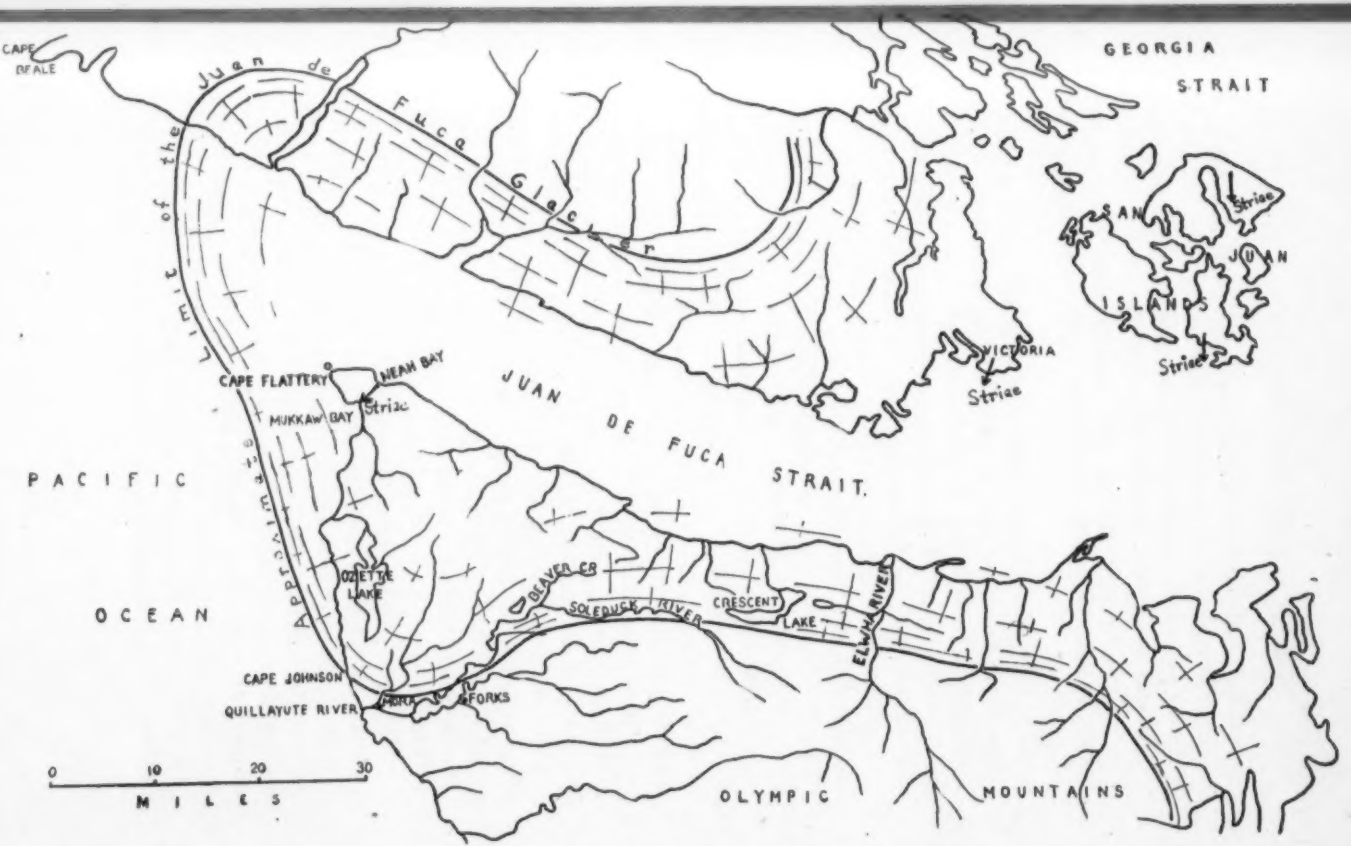

FIG. 1.—Approximate outline of the Juan de Fuca Glacier at its maximum

terminal moraine, and the limits of the Juan de Fuca Glacier as shown in Figure 1 are only approximate.

Glacial till is exposed at the junction of Beaver Creek and Soleduck River, near Pleasant Lake. It is dark gray in color, and contains some finely striated and faceted pebbles. Several granite pebbles, like those in the typical drift of Puget Sound, were found here.

Many bowlders, some of them finely striated, are scattered along the road from Pleasant Lake to Forks, and from Forks almost to Mora at the mouth of Quillayute River.

Granite bowlders with a maximum diameter of 5 feet lie in coves between rocky headlands along the beach immediately north of the mouth of Quillayute River. Their situation and their size render it highly improbable that they traveled along the beach for any considerable distance. The occurrence of granite bowlders here, and between Forks and Mora, indicates that the Juan de Fuca Glacier probably pushed south of the latitude of Cape Johnson.

Two miles north of Cape Johnson there is a sea cliff of glacial till, 25 feet high. The till is light colored and has many pebbles of the same kinds of rock which give Puget Sound drift some of its conspicuous pebbles. The fresh gray color and the shallow oxidized zone above it indicate the Vashon age of the deposit. It is material derived unquestionably from the feeding grounds of the great piedmont glacier whose bifurcation formed both the Puget Sound and Juan de Fuca lobes. Material from the Olympics is either lacking or a negligible quantity. The deposit apparently lies in a pre-Vashon valley whose northern portion contains Ozette Lake.

Between this place and Cape Flattery, at the extreme northwestern tip of the Olympic Peninsula, there are several such sections of till in the sea cliffs. There are also exposures of outwash gravel derived from the same source. The Juan de Fuca Glacier, composed of ice from Georgia Strait, clearly pushed out beyond the present coast. On Vancouver Island it reached at least 15 miles farther west than the longitude of Cape Flattery. Valley trains indicate that the sea stood 30 feet or so above tide at the time of this glaciation. The Juan de Fuca Glacier therefore must have possessed

a tidewater front from a point east of Cape Beale on Vancouver Island to Cape Johnson on the Olympic Peninsula, a distance of about 60 miles. Only Greenland and Antarctica today possess tidewater glaciers of comparable extent. Figure 1 shows the proportions of this lobe and the probable greater deployment at the mouth of the strait, along which the greatest movement of ice doubtless occurred.

The wastage of the Juan de Fuca Glacier was largely by bergs, notably in contrast with that of the glacier of Puget Sound which terminated at its maximum wholly on a land surface. Only the southern margin of the Juan de Fuca Glacier terminated on the land, and only in such a situation could outwash deposits be made at the maximum extent of the ice.

The area invaded by the southern portion of the Juan de Fuca Glacier is drained by Quillayute River. This stream and its tributaries on the coastal plain flow through young valleys cut some 50 feet into a great valley train which extends from Forks to the ocean. At Mora, the altitude of the surface of the valley train is about 30 feet above tide.

At Forks Prairie on the valley train, the gravel is more than 100 feet deep, and wells drilled here have encountered many large bowlders distributed throughout the gravel. Quillayute Prairie, between Forks and Mora, is an isolated plateau-like portion, a few square miles in area and from 75 to 135 feet above the surface of the surrounding plain. It is composed of gravel but has an irregular surface in its northeastern part, strongly suggestive of the presence of blocks of ice during its building. Its isolated position apparently is the result of dissection of an earlier valley train of which it is a portion. From the evidence of the irregular topography in the northeastern portion, the terminal margin of Juan de Fuca Glacier is here mapped as reaching Quillayute Prairie.

A valley train extends down the Soleduck Valley from the base of the Olympic Mountains and joins this broader tract beyond the limits reached by the glacier. The gravel of which it is composed is dark in color, and was derived largely from basaltic rocks and dark-colored sedimentaries. This is typical of most of the débris from this portion of the Olympic Mountains. But scattered

through it are numerous light-colored granitic pebbles and cobbles, which were brought by the Juan de Fuca Glacier over the divide between the Straits and Soleduck River. The Soleduck Valley train was built after the front of the ice had withdrawn eastward to a position somewhere near Lake Crescent. Indeed, aggradation from Olympic débris alone may have continued long after the Juan de Fuca Glacier had retreated entirely from the Soleduck drainage.

The thickness of the Juan de Fuca Glacier was sufficient to enable it to cross the divide between the Straits and the Soleduck valleys. The British Admiralty chart shows summits in this range 4,000 feet high, but the crest in general can hardly average 2,000 feet. Enough of the range was overridden to allow a continuous glacier to spread out on the coastal plain to the south, as shown in preceding paragraphs. Better figures on the thickness of the glacier are to be obtained from features of the Elwha Valley, a few miles east of Crescent Lake.

No granite is known *in situ* in the Olympic Mountains. "Float granite" however occurs in the lower portions of several Olympic valleys draining to Puget Sound and Fuca Strait, and very probably has been derived from Cordilleran ice which pushed up on the flanks and back into the valleys of both the eastern and northern sides of the Olympics.

The river gravel of the Elwha Valley contains scattered granitic bowlders and cobbles at least as far up as Elkhorn Ranger Station, 15 to 20 miles by valley from the Strait. Granitic erratics are abundant along the trail some hundreds of feet above the valley bottom at least 15 miles south of the Strait.

No lobe of ice from the northern glacier could have pushed this far up the narrow Elwha Valley from the lowland occupied by the Juan de Fuca Glacier, and if these bowlders record the presence of ice originally from Georgia Strait, the thickness of the Juan de Fuca Glacier must have exceeded the height of the ridges it had to cross. Hurricane Hills, the highest ridge directly in the path of such invading northern ice, attains an altitude throughout its length of 5,000 feet. Juan de Fuca Strait to the north is 600 feet deep. The Juan de Fuca Glacier opposite the mouth of the Elwha Valley therefore must have been more than a mile thick. This is

70 miles back from the front of the glacier, and indicates an average gradient of its surface of at least 80 feet per mile for that distance. It is probable that the front, which terminated in the open Pacific, was cliffed, and that this gradient must be reduced accordingly.

Based on similar evidence, the surface gradient of the Puget Sound Glacier averaged at least 47 feet per mile for 50 miles back from its front. In both cases, these are but minimum values for the thickness and gradient.

Acknowledgments are due to the Washington State Geological Survey under which the field work was done on which this paper is based.

"SLIDES" IN THE CONEMAUGH FORMATION NEAR MORGANTOWN, WEST VIRGINIA

EARL R. SCHEFFEL
West Virginia University

OUTLINE

FOREWORD
- Geography
- Geology

SLIDES
- Origin and Extent
- Types and Dynamics
  - Primary
  - Fluid
  - Dry

TOPOGRAPHIC FORMS PRODUCED
- Resemblance to glacial forms
- Resemblance to drainage forms

MINOR FORMS ASSOCIATED WITH SLIDES
- "Hoodoos"
- Ice Pinnacles.

TOTALITY OF EFFECTS
- General topographic effect
- Importance as a base-leveling factor
- Influence on drainage
- Similarity of the Conemaugh to other formations

ECONOMIC CONSIDERATIONS

FOREWORD

The purpose of this paper is a systematic discussion of "slides" in and near Morgantown, West Virginia. The abbreviation of the term "landslides" is in accordance with common usage in this locality, slides being a familiar term of everyday speech, so common is their occurrence. Either designation is somewhat of a misnomer as movements are not limited to true sliding.

As this article has a somewhat local bearing the general literature of the subject will not be quoted, though it is but just to state that the writer has received from this source some hints which have helped him in interpretations and comparisons. He

must, however, express his indebtedness to the reports of the West Virginia Geological Survey; also to Professor S. B. Brown, his colleague and chief, who has spent much time in acquainting him with the area. He is especially obligated to Dr. I. C. White, state geologist, and to Mr. David B. Reger, assistant state geologist, for their thoroughgoing review of the paper and constructive criticisms which have been freely used in its revision.

The slides studied occur in the Conemaugh Formation of the Pennsylvanian epoch. This is a series of alternating beds with shales predominating, in this locality approximately horizontal. The total thickness outcropping averages about six hundred feet. All shale members when exposed a short time to weathering agencies break down, if sufficient water is present, into a slippery, claylike mud. This creeps, slides, or even flows until the angle of repose is attained.

Slides, in the aggregate, constitute one of the big factors in the base-leveling of the area. Where numerous they produce a typical topography with features resembling those produced by glaciation and drainage. Less prominent forms frequently associated with slides are the "hoodoos" and ice pinnacles.

The Conemaugh is in a measure representative of several later formations of the Carboniferous, which show closely corresponding topography over much of the northern part of the state where such shaly sediments prevail.

While a single slide is rarely responsible for any great damage, in the aggregate slides become very effective. The total direct and indirect loss amounts to a heavy toll yearly. Some of the damage may be prevented by proper precautions, but the problem is too big for the adoption of absolute preventive measures.

GEOGRAPHY

The area studied with reference to slides is in Monongalia County, West Virginia, about five miles south of the Pennsylvania boundary. Morgantown may be considered the center. Through the area winds the Monongahela River. The Indians recognized the unstable character of the lands adjacent to the Monongahela by this name, which translated means "River of the Caving Banks."

The region is one of mature topography, with a relief averaging about five hundred feet.

GEOLOGY

The geologic maps of the State Survey show exposures in Monongalia County of Carboniferous formations succeeding toward the northwest in approximately parallel belts. The Monongahela River is here practically confined to a course in the Conemaugh, with its valley walls usually showing exposures of most and sometimes all of this formation.

The members of the Conemaugh are approximately horizontal at Morgantown. Elsewhere the dip is prevailingly toward the northwest with interruptions by mild anticlines and synclines. While a decided dip would undoubtedly have some influence on slides, it is believed for the purposes of this paper that the exposed areas of this formation may be considered as horizontal.

The Conemaugh is composed of alternating beds of shales, sandstones, coals, and limestones, with a total thickness varying from five hundred to six hundred feet. Shale and sandstone members vary from a few feet to over fifty feet in thickness. About four feet is the usual maximum for coal or limestone members.

SLIDES

ORIGIN AND EXTENT

Three factors may be considered necessary for the slides discussed. There must be a material which will take the proper consistency, slope, and water. Any of the Conemaugh shales may furnish the material. The degree of slope necessary is practically indeterminable, this varying with water content, thickness, and stratigraphic position of the shale. In extreme cases movements of the more fluid type will take place on nearly horizontal surfaces.

The shales generally are quite fissile, jointed, and slickensided, and tend to become saturated with water, the downward movement of which is successively impeded by the less pervious beds. This water evidently has little effect on the stability of the shales where they are not exposed to the air and excessive temperature changes. Cuts exposing unweathered shales show that these will

hold nearly vertical positions until effectively weathered, which may take from one to several seasons. Under the combined influence of the oxidizing action of the air, water, and temperature changes, especially freezing when water laden, the shales are shattered and comminuted until a slippery claylike mass is produced. Deep freezing is temporarily effective in stopping slide movements, though the result when thawing is a hastening of the process, as the mass more readily breaks away after the aid given by the expansional and contractional movements of freezing and thawing.

The transverse strength of a weathered shale mass is much less than that of the parent body, and when such a mass is sufficiently weighted with water it tends to break away from the latter and so originates the slide. With the breaking away a comparatively fresh surface of the shale is again exposed, so that the process is free to continue indefinitely at the same point or at least until an equilibrium between gravity and tenacity of materials is attained.

Weathered shale on drying becomes hard, and shows no tendency toward movement except in loose surface material.

TYPES AND DYNAMICS

Slides in the Conemaugh may somewhat arbitrarily be divided into three classes, (1) primary, (2) fluid, and (3) dry. These shade into each other or may combine.

1. *Primary.*—These are slides in which the moving mass is highly saturated with water and of the consistency of a thick mud. The primary slide is the first to form and decidedly the most important in totality of effects. The movements are rarely observed though it is believed movements fast enough to be visible are of not infrequent occurrence. Results may often be noted daily in active slides. A new movement of this sort is heralded by a break in the sod, the break tending, with occasionally marked variations, to follow a contour line. The position of this break is further affected by the relative toughness of the sod. Paths, since sod is weak or lacking, offer lines encouraging breaks. A single break is rarely of great linear extent, but the whole face of a hillside may be at times seamed with them. These breaks really

mark a variety of fault plane, the heavily weighted and weakened masses, impelled by gravity, breaking away and slowly dropping and sliding from the parent body. The movement tends to churn the mass rendering it more fluid so that later motion, still unobservable, has apparently an element of flowage. As the slide progresses, the face left bare by its movement widens, sometimes to many feet. This face has usually a much steeper gradient than the mass which previously covered it, offering a ready point of attack by the elements and gravity, so that by repetitions of the sliding process, one starting at the base may be responsible for a successive series to the top of a hillside.

As these slides are closely associated with the ground water, new breaks often show this exuding from their surfaces, their originally somewhat fissile faces soon slaking to a mud-plastered effect. The ground water may be sufficiently abundant to form a stream previously non-existent, which in turn may channel a gully that will determine the drainage flow of the immediate area.

In the same way that slides originate in the fresh shales, later slides repeatedly affect the masses of earlier slides, the process being active only when the material has ample water content.

As an explanation of the common terrace form resulting from slides, the following is suggested: Movement of the slide mass favors its drainage, and when sufficiently drained movement ceases. As drainage is most effective at the front, forward movement lags or ceases at that point first. By pressure of the still undrained rearward mass, the front in its resistance may be forced upward. The result is a hummock with a bare and steeply sloping front, a top of gentle slope which may be even roughly level or dip back toward the hillside, giving favorable conditions for ponding of water and further slide movements; at the rear, the bare steep slope marking the upper border of the surface from which the slide has broken away.

Whether by weakening of their support due to slides on the downslope side, or a crowding due to a faster movement on the upslope side, trees under their influence usually tend to incline downhill. As the roots are anchored in unstable earth, the unbalanced condition of the tree further accentuates this tendency.

When the forward frontal movement ceases or slows the upward crowding of this part may restore any trees upon it to a normal position or even to one inclining uphill. Occasionally trees may be seen inclining uphill on rather steep slopes. The slides producing this result are possibly of greater extent, with less differential and more rapid motion, and a counteracting tendency due to the inertia of the tree, most effective in its upper portion. Leaning trees are not as numerous as one might expect. This is largely due to the fact that they hinder slide movement. Thickly wooded hillsides rarely show such movement.

The vegetation on a slide frequently continues growing as though undisturbed. Between successive seasons of movement the breakage surfaces may become sod covered. Hillsides showing an almost kaleidoscopic change of surface may nevertheless be covered most of the time with a mat of vegetation.

Other things being equal, the thicker a shale the more subject it is to slides, although a thin shale underlain by particularly impervious material may be as troublesome as a thicker layer less favorably situated.

The intervening layers of other rock between shale beds frequently furnish a hindrance to the progression of slide movements uphill, as well as serving to initiate independent slide movements. Such layers, undermined by slides, will in time break off in blocks of size determined mostly by the joint and bedding planes.

2. *Fluid.*—This, the second type of slide, may be considered as an extreme stage of the first. In this type the proportion of water is so great and so thoroughly mingled with the shale mass, that the whole goes downhill in usually visible motion, like a thick fluid. On reaching a surface of sufficiently gentle slope, the heavier materials spread out and settle, leaving the water to drain away from the edge and over the surface like distributaries. These slides, like the third type, are not of great significance.

3. *Dry.*—The dry, or third type of slides, are those with a true sliding or rolling movement downward. On slopes barren of vegetation, movements in the material and drying may so loosen the surface covering, especially of shale flakes, that portions of this will move down in the manner stated unless checked by obstacles

or a lessened slope. If the obstacles are not sufficiently resistant, they may be loosened and may also move forward. Slides of the dry type are frequently observable as an aftermath to the slide movements of the first or second types, which are usually responsible for the barren surfaces upon which the third type originate. Generally the sliding mass is very small in bulk so that this type is probably the least effective in total results. Inasmuch as all the slides in these shales are primarily caused by water saturation, these dry slides are merely secondary effects, tending to re-establish the disturbed angle of repose.

TOPOGRAPHIC FORMS PRODUCED BY SLIDES

Several topographic forms have already been suggested, but it was thought desirable to classify together those which simulate the forms produced by other agencies.

RESEMBLANCE TO GLACIAL FORMS

The irregular surfaces produced by differential motion, especially when the forward part of a slide or combination of slides is crowded up, may give a gently pitted topography favoring the accumulation of water in the depressions. The lakelets thus formed are rarely permanent but may persist throughout the winter. These isolated surfaces suggest modest morainic topography. Sometimes whole hillsides are so cluttered with hummocks of slide masses that they resemble mild kame and kettle areas upon a tilted base. The scattered rock masses on hillsides, while usually more angular, bring to mind the erratics of glaciated country. A hillside from which much slide material has removed takes on a re-entrant character similar to that produced by the plucking action of ice and snow in a glacial cirque. Indeed as suggested by my colleague, Professor Brown, the separation of the slide from the parent mass resembles the bergschrund of a glacier. As bowlders from the resistant formations are frequently mingled in haphazard fashion with the clayey base, the heterogeneous character of glacial till is produced.

RESEMBLANCE TO DRAINAGE FORMS

Upcrowded masses, when of considerable extent, frequently resemble river terraces. These semblances may be hundreds of

feet in length, but rarely more than thirty feet in width. (Successive breaks in a slide mass often result in a series of small terraces or steps which may be likened to step faults.) In some cases the terraces are due to the position of a resistant rock ledge (Figs. 1 and 2). The overlying shales on this having been removed previously

FIG. 1.—Terrace at base of left-hand re-entrant as shown in next view. Slide material has accumulated irregularly on a ledge of the Saltsburg sandstone (in Lower Conemaugh), resulting in a general terrace form with lakelets of precarious life in the hollows.

either by slides or former river action, subsequent slides have spread over the top and flattened to rough conformation with the rock ledge.

Sometimes slide material will accumulate at the base of a slope in the form of a fan or cone, the accumulation probably being the result of a combination of the slide types. A hillside cut marking the source of at least some of the slide material usually leads to it. While these features are still fresh their origin can hardly be questioned. With the passage of time the slide gullies may become

true drainage lines, and the fans and cones become covered with vegetation. They would then be mistaken for forms of stream origin. There is little doubt that many of the so-called alluvial fans and cones in the area discussed have had this history. The later modification may entitle them to their present names. The delta-like products of the fluid slides would also originate such forms.

FIG. 2.—Two huge re-entrants meeting. These are the product of slides which have progressed to near the hilltop. Note the steepening effect produced by slides at their upper limit. The ultimate result, obviously, will be a reduction in the height and gradient of the hill. Slides are still active over the entire surface of the re-entrants; several terrace-like forms are discernible in their midst. The terrace marking the base of the re-entrants, though covered with irregularly placed slide material, has had its form determined by the Saltsburg sandstone which outcrops beneath.

MINOR TOPOGRAPHIC FORMS ASSOCIATED WITH SLIDES

"Hoodoos"[1] and ice pinnacles are frequently found associated with slide materials.

HOODOOS

These are usually abundant on slide slopes after heavy rains. Great numbers will sometimes stand out as distinct columns, but on the steeper slopes the columns with their caps frequently coalesce

[1] See article by Rolf A. Schroeder, *Journal of Geology*, Vol. XXVII, No. 6, pp. 480–81.

on one side with the slope. This form may be so numerous as to give the whole surface of such a slope a peculiar columnar structure. Both kinds of hoodoos are evanescent features.

ICE PINNACLES

These forms are apt to coincide with the melting of snows on steeply sloping fresh slide surfaces, though it does not appear that slope is always necessary. They are tapering columns of ice a few inches in length, coalesced toward their bases, the columns extending with considerable variation at right angles to the surface on which they rest. While the individual pinnacles tend to be straight, many are curved and hooked in curious fashions. They are of principal interest in connection with this paper in that they as well as other ice masses permit the ready transmission of light to the frozen ground beneath where it is absorbed as heat, resulting in a superficial thawing of the surface and a melting of the underside of the ice. No longer properly secured these ice masses, with any enmeshed mud, break off and slide down. This also encourages movement in the thawing muds beneath.

TOTALITY OF EFFECTS

GENERAL TOPOGRAPHIC EFFECT

Taken in the large the topography is little different from a typical area in maturity, though broad hillsides sometimes show huge re-entrants or hummocky surfaces with frequent small terraces. Outcrops of resistant rock frequently indicate their position by steeper slopes even when slide covered.

A number of relatively large discontinuous terraces mark old positions of the Monongahela and tributary streams. These stream terraces may have some association with slide movements. In fresh cuts evidences of stratification, while not infrequent, are less common than till-like coverings. It is tentatively suggested that since the lowering of the streams, movements within the terrace deposits and the addition of slides from the hills may account for the heterogeneous masses so often found.

Where old valleys of somewhat shallow depth are practically confined to shales, the slopes are more mature, as the sliding

continues unchecked by beds of resistant rock. As limestone and coal members are generally weak, the interfering rock is practically limited to the thick sandstone beds.

IMPORTANCE AS A BASE-LEVELING FACTOR

The importance of these slides as a base-leveling factor can hardly be overestimated. Widespread changes are observable as a result of a single season of activity. No other single agency produces comparable results except as associated with this factor. In this sense streams are of highest importance as by their removal of slide masses, a continuency of the movements is permitted.

INFLUENCE ON DRAINAGE

Gully-like forms and similar depressions due to slides are such common features of hillsides or at the edge of slide or stream terraces, that they furnish the readiest lines for drainage of nearby surface areas and for the ground water. It is very probable that most of the minor streams whose courses have been determined under present stratigraphic conditions have had these courses determined in some measure by such depressions.

SIMILARITY OF THE CONEMAUGH TO OTHER FORMATIONS

The Monongahela and Dunkard formations which were laid down following the Conemaugh, show a somewhat similar stratigraphic arrangement with shales of unstable character. Their outcrops, like the Conemaugh, lie in the Alleghany Plateau. Gently dipping northwest, with usually mature topography, slide conditions throughout their outcropping extent do not differ greatly from those of the Conemaugh, though the Dunkard shows some interesting differences.

ECONOMIC CONSIDERATIONS

While most of this territory is subject to surface modifications on account of slides, the damage within the city of Morgantown is less serious than might be inferred. This is due in large measure to the situation of most of the city on the several comparatively level terraces of the Monongahela River and tributaries. By utilizing the connecting slopes as well as some of the land rising

above the well-defined terraces, the city has avoided extending its territory excessively. The connecting slopes have caused little trouble in the business district. This is in part due to the fact that the terrace positions were largely determined by the resistant rock. The removal of slaked shales, grading, and the protective effect of building and paving operations have all helped in preventing serious trouble. In the outlying territory dwellings built on

FIG. 3.—Walls and steps pushed forward as a result of slide movements. The house in the foreground is in immediate danger. Note jagged edge of broken brick walk leading to house in the rear. As is frequently the case, the sliding masses have produced a terrace-like form, with the vegetation growing on its top but little disturbed. Many months were required to produce the foregoing result.

terrace slopes and on the upper hill slopes are sometimes endangered by slides, and precautions have to be taken to prevent their destruction. The most effective preventive of trouble is the exercise of foresight, the position a house is to occupy being considered with reference to this difficulty. Sometimes thick retaining walls are built at the time to insure safety. That such walls prove inefficient at times is shown by the accompanying figure. Some

lots plotted for building purposes are totally unfit for such use, a fact which usually becomes apparent before construction is started. In a few instances the grading of roads, or changes of drainage by fillings or other causes, has been charged with starting slides endangering structures. Such instances have usually resulted in lawsuits to determine the influence of such changes and also to place responsibility.

FIG. 4.—Slide partially blocking roadway. The entire face of the slope above the slide is bare to a height of about forty feet, the result of recent slides.

The greatest source of trouble comes from the roads leading out of the city. As the terraces on which the city is built are fragmentary, roads cannot follow them for great distances. If outlying districts are to have communication with the city, the building of roads along or at the base of hillsides is unavoidable. While poor engineering judgment is sometimes shown in locating the roads, with the best of skill the ultimate damage can only be lessened. The present roads, including several regraded and paved within the last few years, have suffered repeatedly, sometimes by block-

ing caused by upslope slides, sometimes by caving, the result of downslope slides. The most obvious remedy for the former is to reduce the slope by cutting away on the uphill side, and to produce the same result by filling in on the lower side. On the new slopes so made the growth of vegetation should be encouraged. It might prove practicable in extreme cases to prevent saturation of the trouble-making shale by well-planned drainage. Heavy retaining

FIG. 5.—Slides have undermined the brick-paved road at this point. The line of dirt through the center of the road fills a crack and reduces the gradient between the sides of the offset. At the far end marked by the position of the man, half the road has dropped to such an extent as to require blocking off.

walls should be successful in some instances. These remedies may be considered applicable only in extreme cases, or with such portions of the road where the trouble is due to the cut made in grading. The total avoidance of damage would mean a cost in preventive arrangements greater than the total of prospective damage.

Electric railroads are subject to the same conditions as the highways. The steam railroads in the immediate vicinity of

Morgantown are built on natural or artificial terraces cut in the Buffalo sandstone, one of the lower Conemaugh members. As the lower part of this massive sandstone forms the river bottom, the railroads here are free from undermining, but subject, especially when following close to the hillsides, to occasional slides from above. The removal of these causes immediate expense as well as delays. By the liberal use of watchmen in deep cuts and frequent "slow orders" in times of excessive rainfall, few wrecks are fortunately chargeable to this cause. A better understanding of the shales would result in relocating parts of the tracks.

As slides are much more frequent in seasons of abundant rainfall than in seasons of light fall, the damage to roads and various structures and loss by delays increases or decreases accordingly. The past year (1919) was one of abnormal rainfall, roughly about one-fourth greater than the average, the fall months having more than their share of the excess; consequently the year and especially the latter months proved unusually costly. The generally slow movement and small volume of the individual slides have meant that private parties have rarely suffered disastrous losses. While no total can be estimated for the average yearly loss to the community, there is no question that this would amount to a big sum.

An indirect loss, though much more than all others in the aggregate, is that caused by the withdrawal of farmland from cultivation. Slopes not too steep for the plow under light rainfall conditions, when charged with water may start movement which a vegetative covering would have checked. Such slopes are best reserved for grazing or forest growth. This is well understood by farmers, and very little land except flood-plains, terraces, and hilltops is ever plowed. The effect of the Conemaugh in limiting cultivation is well indicated by the fact that other and especially older formations in West Virginia permit cultivation on much steeper slopes than allowable in the Conemaugh, without sliding.

The shale soils, where they can be used, are generally productive. Especially is this true when they have a pronounced lime content, either native or infiltered from higher beds.

The frequent undermining of sidewalks along the roads on the edge of the city would seem to furnish a fruitful source for accident,

likewise the obstruction or falling in of roads. The frequency, however, is itself the safeguard, the population having become educated to the danger, and consequently taking proper caution. The injuries from such causes have been few.

It may be noted that slides have never been of sufficient extent to interfere with the use of the Monongahela River since rendered navigable.

The only direct economic benefit from the slides lies in the fact that brick, ordinarily made by grinding the shale, can be made of almost equally good quality and less expense for handling from the slide material. When work in the shale is interfered with by slides, the material in these is used.

The shales worked at present near Morgantown are near the base of the Conemaugh, though shales higher in the formation are frequently used elsewhere. Formerly brick was made from river-terrace clays, these clays resulting doubtless from the assortment of shale muds reaching the rivers as slides and from direct stream action.

A REPLACEMENT OF WOOD BY DOLOMITE

S. F. ADAMS
Stanford University

A score or more minerals are known to have replaced wood. Cases of most of these types of replacement were recorded by J. R. Blum[1] during the years 1847–79. Since 1879 there have been few additions to the list of wood-replacing minerals as given by Blum. To my knowledge, replacement by dolomite has not before been mentioned. For this reason, the accompanying account has been made as complete as possible.

In the known replacements of wood chalcedony is undoubtedly the most universal petrifying mineral. Fine examples of this kind of replacement are found in the petrified forests of Arizona, where very large tree trunks have been completely agatized.[2] Petrifactions of this type come from localities in Colorado, Utah, California, and from the Yellowstone Park. I have at hand an unlabeled specimen of petrified wood which is thought to come from Arizona, in which the wood is largely replaced by quartz. A thin section of this specimen shows anhedral quartz crystals which include sometimes a dozen well-outlined wood cells. The general character of the quartz is similar to that to be described on a later page. Wood opal replacing entire tree trunks is found in Hungary; nor is it uncommon in this and other countries. Precious opal, usually as a late development after common wood opal, is known to come from Australia and from a deposit in Nevada, where the opal is being recovered for commercial purposes. Blum mentions opalized wood with an incrustation of hyalite.

Replacements by calcite and aragonite have been recognized in many places. The strong crystallization of these two minerals

[1] J. R. Blum, *Pseudomorphosen des Mineralreichs*, Nachträge, 1, 2, 3, 4.

[2] G. P. Merrill, "The Fossil Forest of Arizona," *Am. Mus. Jour.*, Vol. XIII, pp. 311–16.

usually obliterates the cell structure of the wood. An interesting case in which the wood tissue is well preserved by calcite has recently been described by C. W. Greenland.[1] Fragments of wood and plant remains petrified by pyrite, and marcasite are recorded from carbonaceous formations of many districts. Blum describes replacements of wood by barite, from the Lias chalk beds of central Germany; by cinnabar, from Bavaria; by fluorite, from Saxony; by sulphur, from Italy; and by malachite and azurite, from the Urals and West Africa. The same author also records replacements of wood or plant remains by gypsum, phosphorite,[2] hematite, limonite, siderite, sphalerite, galena, chalcopyrite, and chalcocite. He mentions a case in which wood tissue is well preserved by a kaolin-like substance most closely resembling halloysite. Blum also discusses replacements of wood, from near Moutiers in the French Alps, by a mineral closely resembling talc, and compares this mineral with some pyrophyllite from the Thuringen district in Germany. The pyrophyllite, however, is not described as replacing wood. Grabau[3] mentions chlorite as replacing plant remains.

In an article on the "Red Bed" type of copper ores, Rogers[4] lists as occurring in petrified wood: hematite, pyrite, bornite, chalcocite, chalcopyrite, covellite, melaconite, limonite, malachite, azurite, and quartz. Of these, only hematite and pyrite are considered as directly replacing wood.

The dolomitized wood herein described belongs to the mineral collections of Professor A. F. Rogers, of Stanford University, to whom I am indebted for the privilege of describing it as well as for suggestions as to the description itself. The specimen was found in 1916 in the Midway Oil Field, Kern County, California, by C. R. Swartz. It comes from what is locally known as the McKittrick formation, which may include sediments of upper Miocene, Pliocene, and Pleistocene age.[5]

[1] C. W. Greenland, *Econ. Geol.*, Vol. XIII, pp. 116–19.

[2] Probably impure collophane.

[3] A. W. Grabau, *Principles of Stratigraphy*. A. G. Seiler & Co., 1913.

[4] A. F. Rogers, *Econ. Geol.*, Vol. XI, pp. 366–80.

[5] Arnold and Johnson, *U.S.G.S. Bull. 406*.

The hand specimen measures four by three by two inches (Fig. 1). Worn and rounded corners indicate that it is float, for which reason the horizon from which it came cannot be more definitely established. The specimen is of two distinct colors, a buff outer part which may correspond to sapwood, and a dark-gray inner part which may have been heartwood. The former is dolomite, the latter silica. Qualitative analysis of the dolomite gave roughly half as much magnesium as calcium and an appreciable, though not large, amount of iron. The general buff color throughout the dolomite is due as much to the oxidation of this iron as to organic matter. Both Professor D. H. Campbell and Professor Leroy Abrams, of Stanford University, have determined the wood as that of gymnosperm and almost assuredly coniferous. Due to the imperfect preservation of fiber, further identification was not made.

FIG. 1.—Wood replaced by dolomite. Gray part is compact dolomite showing radial lines and small black siliceous dots, which may represent location of resin ducts. In center of specimen is coarser dolomite in rhombs and compound groups. Black portion, showing annual rings, is quartz. (Slightly reduced.)

In the center of the specimen is a spot of darker brown color containing rather coarse dolomite crystals. In this place a feature which has been described by E. T. Wherry[1] (in an account of a petrifaction by calcite from Yellowstone National Park) is rather prominent, e.g., the individual or compound convex-bordered crystals in a siliceous matrix. On either side of the central darker area is the buff mass of dolomite replacing the outer portion of the

[1] E. T. Wherry, *Proc. U.S. Nat. Museum*, Vol. LIII, pp. 227–30.

specimen. The most noticeable feature in this part is the parallel radial lines of buff dolomite. Adjoining lines usually are separated by fine brownish black silica.

Small dolomite crystals grouped radially about a center of silica also can be seen in this part of the specimen. These groups are made prominent in the hand specimen by the black silica cores. They occur with apparent regularity throughout the dolomite, and

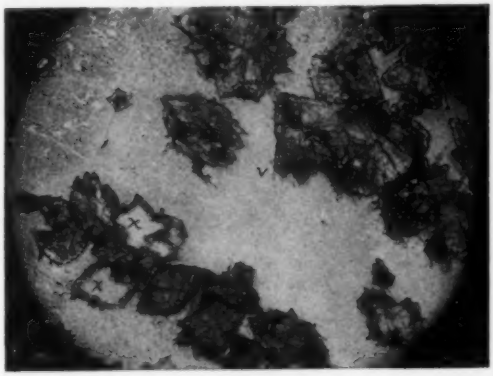

FIG. 2.—Thin section showing compound dolomite crystals in siliceous matrix. Replacement of dolomite by silica is illustrated around places marked "*x*." White central part (at "*x*") is a hole in the slide where the dolomite has pitted out. The fringe around the hole is silica, surrounded by the darker organic matter excluded by the dolomite during growth. This same effect can be seen around most of the rhombs. This section also shows second generation dolomite developing along the edges of the older rhombs as at "*v*." ×9½.

it was at first suggested by Professor Abrams that they might mark the location of resin ducts. This seems doubtful unless the outer part of the specimen is a petrifaction of bark. However, recognition of wood structure throughout the dolomite is at best largely a guess.

Annual rings are not well preserved in the dolomite. In the dark-gray siliceous part of the specimen, however, annual rings are prominent. They are marked by the gradual darkening of color from spring growth to winter. In one or two places there are

cavities with inwardly projecting quartz crystals. Small euhedral quartz crystals have developed on the outside of the siliceous portion of the material.

Under the microscope the individual dolomite crystals are first to attract attention (Fig. 2). The well-developed rhombs usually average about one millimeter on the long diagonal. The dominant form is the unit rhombohedron $r(10\bar{1}1)$, sometimes modified by

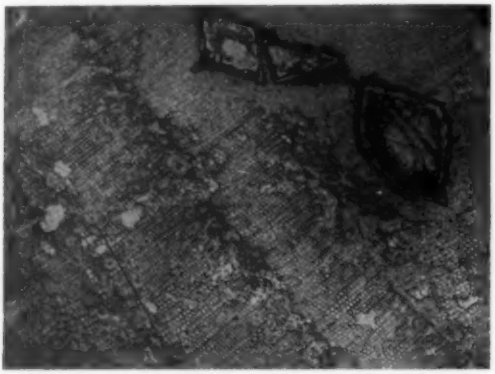

FIG. 3.—Thin section of corroded dolomite rhomb in quartz ground-mass. Also showing patchy retention of cell outlines, especially along annual rings. Notice apparent distortion of cells bordering the larger dolomite rhomb. $\times 21\frac{3}{4}$.

$e(01\bar{1}2)$. These crystals neither include nor preserve any cell outlines. A dark-brown rim around the edges indicates that they have excluded the woody material. Replacement of the crystals along borders by finely crystalline silica leaves a corroded dolomite core surrounded at a little distance by a brown organic halo, as the development of the silica does not affect the position of the organic matter (Fig. 3). In a few cases, surrounding groups of cells seem to have been squeezed by the growth of the rhombs. Cells are usually misshapen near the annual rings. However, one or two occurrences can be seen in which cells, bordering dolomite crystals which lie entirely within the customarily well-developed spring growth, are distorted as if by pressure from the crystal (Fig. 4). This is an indication of the formation of the

dolomite before the surrounding silification. In general, cell outlines are not evident near the borders of dolomite rhombs. Had the dolomite been a replacement of silica, one would expect to find the cell outlines in the silica as well preserved in the immediate neighborhood of the rhombs as elsewhere. The exclusion of woody material is also evidence of the early crystallization of this dolomite.

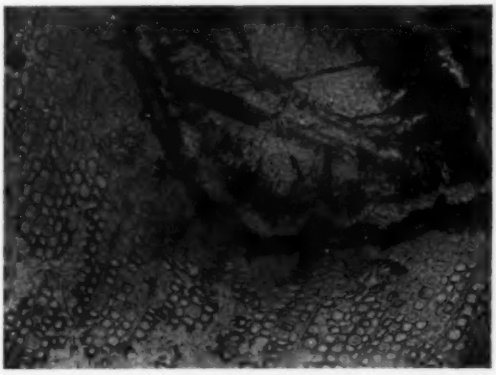

FIG. 4.—High power view of rhomb in Figure 3, showing dolomite core, organic rim, and silica fringe separating the two. Also shows distorted cells. ×76½.

In the main mass of buff dolomite the crystals are slightly smaller than the rhombs just mentioned, and they rarely show crystal outlines. With magnification the thin section appears to be a compact mass of rather even fine-grained crystals, usually about twice as long as wide. Many crystals appear to be twinned. No polysynthetic twinning was noticed either in the thin section or in fragments. An approach to cyclic twinning is occasionally seen, but commonly the apparent twinning is of a simple contact nature. However, the presence of twinned crystals was not proved.

The dolomite crystals are sometimes arranged side by side in long rows; opposite them is a similar row; and along the center where the rows touch are two imperfect chains of distorted cell outlines. The rows are always arranged radially with respect

to the replaced wood as a whole. Although these "chains of cells" include varied sizes and odd shapes, it is safe to say that they are a relic of the original vegetable fiber. The size of the cells in these chains varies from 0.02 mm. to 0.07 mm. in diameter and averages 0.04 mm., which is a range in size and an average also true of cell outlines well preserved by silica. Occasional cells are replaced by individual dolomite crystals which do not extend beyond the cell walls, and still other cells show evidence of secondary enlargement of dolomite, proceeding outward from the cell as center. Cell outlines in dolomite are not often retained except in or near the cell chains. The parallel row arrangement is repeated throughout much of some of the thin sections. It is this arrangement which causes the radial lines of buff and black as seen in the hand specimen. The fine black lines are composed of a late silica which develops most readily between the abutting ends of the dolomite crystals. An explanation for this phenomenon which seems tenable is that the dolomite started crystallization simultaneously along somewhat widely spaced radial lines; that in the first crystallization some of the cell outlines were preserved; but that in the subsequent growth wood structure was largely obliterated. Judging from the secondary enlargement of dolomite with a cell as a center, the initial crystallization occurred within the cell, in some cases at least.

Often the dolomite crystals are grouped radially with a small center of finely crystalline silica of the same late type as just mentioned. The silica, of course, is a development subsequent to the radial growth of the dolomite. The siliceous cores of these groups are seen as fine black dots in the hand specimen. Extinction in sequence often occurs in the radially grouped dolomite, and when combined with simultaneous extinction in opposite sectors, gives the group a rough spherulitic appearance.

Thin sections of what has been called the heartwood show the best retention of cell structure and annular rings. For the most part, the replacing mineral is quartz.[1] Crystals are usually

[1] The exact relations of quartz, chalcedony, fibrous, and other forms of silica have not been settled. In this article the identification of quartz as such is made easy by its occasional euhedral form. The chalcedony to be mentioned later was so called on account of its lesser refractive index than quartz and negative elongation.

anhedral and of a fairly uniform size in any one part of the thin section, although the average size for the different parts of the specimen may vary from very small to a maximum width of about 0.2 mm. In general, it is the rule for one quartz crystal to contain several wood-cell outlines. As before stated the average diameter of cells is 0.4 mm., with a range of from 0.02 mm. to 0.07 mm. In longitudinal sections the quartz is usually elongated in the direction of the wood fiber, showing that the growth of crystals has been influenced by cell structure. Distinct crystal outlines with an occasional hexagonal cross-section are noticeable in several places throughout the anhedral quartz. They are better-developed individuals belonging to the same silification. As may be seen in one of the accompanying photographs (Fig. 3), retention of cell structure is patchy. The best-developed quartz crystals occur on the borders of those places in which no cell structure is evident. They give the appearance of having grown into an open space, or at least into a decayed spot, where there was nothing to resist their assuming idiomorphic form. At their roots these crystals also inclose cell outlines.

Secondary enlargement of the euhedral and subhedral crystals is seen in several places. A rough radial grouping occurs in some of the quartz. Extinction in sequence often gives these groups the same coarsely spherulitic appearance as in the dolomite. Wavy extinction is common in many crystals. In one thin section cell outlines are well preserved by another form of silica. This silica is very fine grained, fibrous, often spherulitic, with very weak double refraction, about the same index of refraction as quartz, and of negative elongation.

Late silica and dolomite are found in veinlets and cavities. In several small veinlets which cut both siliceous ground-mass and early dolomite crystals, banding by alternating quartz and dolomite occurs. Dolomite also is found in patches throughout the quartz replacement of heartwood. In cavities it is often in the center as a filling around projecting euhedral quartz crystals. A very prominent occurrence of this late dolomite is as an enlargement, although not in crystallographic orientation, of the older rhombs and dolomite crystals.

The later silification develops with this dolomite as a replacement of the previously formed quartz and dolomite as a cavity and vein filling, and as an incrustation. That it actually replaces the earlier quartz is not certain, but its replacement of dolomite is manifest in the corroded rhombs separated from their excluded organic halo by silica. Chalcedony and quartz occur in this silification. Quartz predominates. It occurs in subhedral crystals in veinlets, presenting a microscopic comb structure, or as cavity filling, in which case it has developed from the walls inwardly as in a geode. In both of these cases it often shows zonal lines. It replaces the dolomite around the borders, and, especially in the case of the compound dolomite groups, it begins replacing in the center of the group as well as along the edges. The development between parallel rows of dolomite crystals has already been mentioned. The chalcedony and fibrous silica are found in the centers of filled cavities, in veinlets, and as a replacement of dolomite.

Another very interesting late development is that of minute patches of an opaque gray metallic mineral, taken to be hematite, but in too minute amounts to test. This appears in a polished surface in veinlets and patches and in one case in a small rhomb as if it were a pseudomorph after dolomite.

In conclusion: dolomite seems to be the earliest replacing mineral. The small area of large-sized rhombs is taken to be the result of replacement in a partially rotten or injured spot in the wood. The outer part of the specimen was replaced by a finer-grained dolomite, but without retention of much of the cell structure. The curious arrangement of crystals in rows points to initial crystallization along radial channels. What furnished these channels is not clear. The distance between rows is greater than the spaces between medullary rays. Also, the channels have longitudinal extent, which leads to the possible hypothesis that they were caused by closely spaced radial cracks.

From the general character of the petrification it appears that crystallization took place rather slowly along certain lines, later spreading throughout the wood and destroying most of the cell outlines. For some reason these solutions gave out before complete dolomitization, for the inner part of the specimen shows no evidence

of having been attacked by dolomite. Blum describes a petrifaction by opal in which the outer part is opal, whereas the core is unaltered wood, showing that replacement progressed from the outside toward the center. It may be that in the case in hand petrifaction occurred while at least a complete cross-sectional fragment of the wood was intact, and that dolomitization started from the outside and developed inwardly. The solutions containing the carbonate then gave place to others with silicic acid which permeated the heartwood and caused its silification. Cavity and crack fillings, and rearrangements, followed at some time later.

A DISCUSSION OF "NOTES ON PRINCIPLES OF OIL ACCUMULATION" BY A. W. McCOY[1]

CHESTER W. WASHBURNE
New York City

In many ways this is one of the most interesting articles on the accumulation of oil that has appeared. I have long held many of the conclusions reached by Mr. McCoy in this paper, and it is a great pleasure to find these ideas corroborated by his experiments, which have been cleverly conceived and executed. It is unnecessary to reiterate the good points of the paper. It will be more useful to call attention to some of the more doubtful conclusions, in the hope that further study by McCoy and others may clarify these points.

Origin of oil.—The first experiment shows that liquid oil may be formed by the deformation of oil shale which previous to deformation contained only solid organic materials. McCoy states that "no appreciable amount of heat was developed." It seems to me impossible to deform the steel cylinders and to crush and shear the inclosed shale without causing an appreciable increase in temperature. If the experiments had been carried out in cylinders under water and if the temperature of the latter had been measured after the completion of the experiment, I believe McCoy would have found that there had been a material loss of energy in the form of heat. Shale is notoriously a poor conductor of heat. Therefore there must be a material rise in temperature along every plane of shear. As stated by McCoy, differential movement in shales probably is an important cause of the alteration of solid organic matter into oils. However, it is probably heat rather than pressure which causes this alteration. Heat is a common cause of the dissociation of various molecules. Pressure

[1] *Jour. Geol.*, XXVII (1919), 252–62.

never has been known to split a molecule of any kind; nor has mere "mechanical energy." It will require an entirely new concept of the molecule to assume that a mechanical shear can cut a molecule. Only vibratory forces, like heat, light, electricity, and subatomic radiations are now thought to be capable of penetrating molecules. The mechanical energy of McCoy's experiment must have been transformed into one of these other forms of energy before it could split the molecules of organic solids.

The formation of oil is a process which results in a great increase in the volume of the original solid material, which is converted into new solids, liquids, and gases. Pressure therefore is a condition which might be expected to retard rather than accelerate the process. In fact, the distillation experiments by Engler have shown that pressure retards the thermal dissociation of fats. The principal effect of pressure in this connection is to cause an inward shift in the point of splitting within the solid organic molecules. High pressure causes the splitting to take place farther from the surface of the molecules, resulting in the formation of less gas and coke and of more of the intermediate or liquid products. The same phenomenon also appears to rule the operation of the high-pressure stills of cracking plants, decreasing the amount of gas and residue in the product, and increasing the amount of gasoline, and under certain conditions increasing the yield of kerosene. Therefore high pressure in the rocks probably is a useful and essential condition for the formation of oil. It is not, however, the main cause of the formation of oil. There is nothing in this experiment to indicate that heat is not the principal agent that splits solid organic molecules into gases, oils, and carbon-rich residues such as asphalt.

A slight increase in temperature may be enough to initiate the process, after which the release of the endothermic heat of formation evolved by the splitting of the first molecules would increase the temperature of adjacent molecules. Thus, when once initiated by any cause, the process of thermal dissociation of solid matter into oil, gas, and black residue would tend to perpetuate itself and to increase, like spontaneous combustion, as long as there was an abundant supply of endothermic organic matter present.

There is reason to doubt that the known types of oil shale had anything to do with the formation of oil. Many of these shales, as in Scotland, New Brunswick, and New South Wales, have undergone such severe deformation that if their contents were capable of being converted into crude oil by such means, it is hard to understand why they have not all been completely converted. Yet in these fields there is no indication that any of the oil-shale has been altered into crude oil. Reagents will not extract more than a trace of oil from them. The oils obtained from them by distillation consist largely of unsaturated hydrocarbons which could not be converted into the better types of natural crude oils except by hydrogenation. Hydrogenation seems impossible in nature. Moreover, the collection of numerous analysis by Hoefer shows that the oil shales of various ages exhibit an increasing ratio of carbon to hydrogen in the samples from older rocks, indicating that the course of metamorphism of oil shales is very similar to that of coal, and that the organic matter in these shales tends to become harder and richer in carbon with the passage of time. There is some suggestion that the oil shales of Colorado and Utah and the Cannel coals of Kentucky will be found to be of this same general type. The substances in shale which have been converted into crude oils very likely are of a nature somewhat different from the organic matter in the types of oil shales that have been studied. The nature of this difference is a problem for future investigation. This point may be determined by distilling unaltered marine oil shales, preferably of the Late Tertiary, and by studying the decomposition of the fats and waxes of modern organisms.

Oil migration in wet sand.—Mr. McCoy's third experiment shows rather clearly that under ordinary temperatures oil will not migrate away from the larger pores in a sand under the influence of gravity aided by rather strong circulation of water. The capillary forces involved are strong enough to hold the oil in the larger pores against the influence of gravity and water circulation.

It would be very interesting to have this experiment repeated under the temperatures that prevail at depths of a few miles, where capillary forces are greatly reduced. The viscosity of the oil also is reduced. A useful point has been established by

McCoy in showing that under common surface temperatures a comparatively vigorous circulation of water will not remove oil from the larger pores of the sand. It does not follow, however, that water circulation could not do this at depths of two or three miles, which does not exceed the probable thickness of strata that formerly covered many oil sands. Further experiments under appropriate higher temperatures are needed to show that gravity alone could not produce anticlinal accumulation in sands buried under a few miles of rock.

Anticlinal accumulation.—Mr. McCoy appears to believe that the lateral migration of oil in sands is of minor importance. He believes that the anticlinal accumulation, which characterizes most fields, is due primarily to migration along nearly vertical shale joints, which are most abundant theoretically on the crests and limbs of anticlines.

There is an asymmetrical distribution of oil in the Cushing and Yale fields, Oklahoma, and in other places where the basin-ward limbs carry the most oil, and carry oil to the lowest structural elevations. This indicates that lateral migration up the slope of sandbeds is an important element in anticlinal accumulation. On the other hand, the frequent distribution of oil in various sands, one above the other, and all above the probable source, as in the Wyoming domes, indicates the importance of joints across the shales. The relation to faults of the principal fields in Kentucky and northern Louisiana bears similar testimony.

The accumulation of oil in the sand of the Ranger field, which is "dry" outside of the producing territory, also suggests the inadequacy of lateral migration in the sands. The occurrence of oil in fractured chert on top of the Santa Maria anticline in California must have been due wholly to migration along nearly vertical crevices, since it would be impossible for oil to move laterally through the hard, dense, unfissured chert on the lower parts of the anticline. Wells drilled on the flanks of this anticline showed neither oil nor water when they passed through the chert horizon.

In spite of these interesting experiments it seems that the time has not yet come to abandon wholly our previous ideas that an

important part of anticlinal accumulation is due to migration up the slope of the sand. The experiments are important in showing the difficulty or impossibility of such migration under the low temperatures of very shallow depths. The experiments by McCoy show that we should give more thought to the importance of anticlinal crevices in shale.

REPLY TO DISCUSSION BY C. W. WASHBURNE ON "NOTES ON PRINCIPLES OF OIL ACCUMULATION"

A. W. McCOY
Bartlesville, Okla.

In reply to Mr. Washburne's discussion of this paper, each of his main points will be answered briefly in the following paragraphs.

The first criticism offered is that as to the origin of liquid petroleum from solid hydrocarbon waxes (commonly called kerogen) in the shale. The original paper states that "no appreciable amount of heat was developed," implying that the amount of heat developed was in no way comparable to the necessary distillation temperature for those hydrocarbons. The heat developed was not great enough to melt a thin coat of paraffin which had been placed around the bulging zone of the cylinders.

Moreover, the paper does not state that pressure was the direct cause for this change, but definitely says that pressure alone can cause no change in the material. It suggests that this change can take place in regions of differential movement, and that such zones are the only areas where liquid oil is likely to be made. Field observations indicate that such a condition exists, but a discussion of the point would necessarily be too long for this short statement. Pressure and release of pressure are essential for differential movement. The latter action is probably the real cause for any chemical change, whether resulting directly from developed heat or otherwise.

Mr. Washburne's suggestion that the chemical action of forming liquid petroleum from solid waxes is an exothermic one, and when once started will generate heat to carry on the action, neither agrees with the work of Engler and Hoefer, nor with the evidence gathered by the author from laboratory distillations. Before this

point could be considered seriously it would be necessary for Mr. Washburne to show the chemical equations of the action, the amount of heat absorbed or given out by each combination, and the resulting heat from the summation.

From the literature available, the author has been unable to secure enough detail on the geology of the Scottish oil shales to determine to what extent the shales have been altered, and how tests for liquid oil have been carried out in relation to such places. It is a well-known fact, however, that there are a few veins of gilsonite and other heavy hydrocarbons in joints or small fault planes of the Colorado-Utah oil shales, although they have not been altered by any widespread movement. These shales, as well as those of Scotland, are most probably non-marine in origin and differ somewhat from the marine type of bituminous shales which furnish petroleum.

The suggestion that the experiments should be carried out under pressures and temperatures prevalent for depths of several miles is good but unnecessary. At any given depth the temperature could be estimated, so that with temperature and the size of the openings known, it is merely a physical problem to determine the action. Pressure has such a small effect on surface tension that it may be neglected. Moreover, the majority of the oil sands in the Mid-Continent Field have never been buried more than five or six thousand feet and the actions at such depths are similar to those described in the experiments.

Mr. Washburne states that the asymmetrical distribution of oil in the Cushing and Yale fields indicates that lateral migration up the slope of sand beds is an important element in anticlinal accumulation. The author disagrees with this statement, as it is only a popular notion among oil geologists which has never had any substantial, scientific backing. On the other hand, the arrangement of the oil in these pools has a marked relation to the stress lines of the region and can be explained satisfactorily by this method as in the other pools of the mid-continent. Such an explanation would necessarily be long and does not directly refer to the subject of the original paper.

To say that the time has not yet come to abandon previous ideas concerning oil migration up the slope of a sand is only helping to cover a weak link in the anticlinal theory, and passing the responsibility of correcting questionable points before precedent has established a dangerous stone in the progress of the new science. Oil geology is now undergoing a crisis in its history, so the time is ripe for each follower in the science to face the facts squarely and to strive with an unbiased mind to reach the correct solution of oil accumulation phenomena. One of the world's greatest industries demands, by its expenditures of millions, that those offering scientific interpretation endeavor to gain the clearest and most logical principles based upon the maximum of details.

The discussion of this article has been most welcome.

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